TABS A-D

REDACTED IN THEIR ENTIRETY

TAB E

Designation: F 558 – 06

An American National Standard

Standard Test Method for Measuring Air Performance Characteristics of Vacuum Cleaners[1]

This standard is issued under the fixed designation F 558; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers procedures for determining air performance characteristics of commercial and household upright, canister, stick, hand-held, utility, and combination-type vacuum cleaners having provisions for attaching a hose and incorporating a series universal motor. This test method can be applied to the carpet cleaning mode of operation.

1.2 These tests and calculations include determination of suction, airflow, air power, maximum air power, and input power under standard operating conditions (see Note 1). The nozzle mounted on plenum testing is an ideal air performance measurement and is not intended to represent the actual air performance during carpet or floor cleaning.

NOTE 1—For more information on air performance characteristics, see Refs (1-6).[2]

1.3 The foot-pound-inch system of units is used in this standard. The values in parentheses are given for information only.

1.4 This standard may involve hazardous materials, operations, and equipment. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* A specific precautionary statement is given in Note 2.

2. Referenced Documents

2.1 *ASTM Standards:* [3]

E 1 Specification for ASTM Liquid-in-Glass Thermometers

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

F 431 Specification for Air Performance Measurement Plenum Chamber for Vacuum Cleaners

2.2 *AMCA Standard:*[4]

210-85 Laboratory Methods of Testing Fans for Rating

2.3 *IEC Standard:*[5]

IEC 60312 Ed 3.2 Vacuum Cleaners for Household Use—Methods of Measuring the Performance

3. Terminology

3.1 *Definitions:*

3.1.1 *air power, AP, W, n—in a vacuum cleaner*, the net time rate of work performed by an air stream while expending energy to produce an airflow by a vacuum cleaner under specified air resistance conditions.

3.1.2 *automatic bleed valve, n*—any device a part of a vacuum cleaner's design which automatically introduces an intentional leak within the vacuum cleaner's system when manufacturer specified conditions are met.

3.1.3 *corrected airflow, Q, cfm, n—in a vacuum cleaner*, the volume of air movement per unit of time under standard atmospheric conditions.

3.1.4 *input power, W, n*—the rate at which electrical energy is absorbed by a vacuum cleaner.

3.1.5 *model, n*—the designation of a group of vacuum cleaners having the same mechanical and electrical construction with only cosmetic or nonfunctional differences.

3.1.6 *population, n*—the total of all units of a particular model vacuum cleaner being tested.

3.1.7 *repeatability limit (r), n*—the value below which the absolute difference between two individual test results obtained under repeatability condition may be expected to occur with a probability of approximately 0.95 (95 %).

3.1.8 *repeatability standard deviation (S_r), n*—the standard deviation of test results obtained under repeatability conditions.

3.1.9 *reproducibility limit (R), n*—the value below which the absolute difference between two test results obtained under

[1] This test method is under the jurisdiction of ASTM Committee F11 on Vacuum Cleaners and is the direct responsibility of Subcommittee F11.22 on Air Performance.

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[2] The boldface numbers in parentheses refer to the list of references appended to this test method.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from Air Movement and Control Association, 30 West University Dr., Arlington Heights, IL, 60004.

[5] Available from the IEC Web store, webstore.iec.ch, or American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

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reproducibility conditions may be expected to occur with a probability of approximately 0.95 (95 %).

3.1.10 *reproducibility standard deviation (S_R), n*—the standard deviation of test results obtained under reproducibility conditions.

3.1.11 *sample, n*—a group of vacuum cleaners taken from a large collection of vacuum cleaners of one particular model which serves to provide information that may be used as a basis for making a decision concerning the larger collection.

3.1.12 *standard air density, ρ_{std}, lb/ft^3, n*—atmospheric air density of 0.075 lb/ft^3 (1.2014 Kg/m^3).

3.1.12.1 *Discussion*—This value of air density corresponds to atmospheric air at a temperature of 68°F (20°C), 14.696 psi (101.325 kPa), and approximately 30 % relative humidity.

3.1.13 *suction, inch of water, n—in a vacuum cleaner*, the absolute difference between ambient and subatmospheric pressure.

3.1.14 *test run, n*—the definitive procedure that produces the singular result of calculated maximum air power.

3.1.15 *test station pressure, B_p, inch of mercury, n—for a vacuum cleaner*, the absolute barometric pressure at the test location (elevation) and test time.

3.1.15.1 *Discussion*—It is not the equivalent mean sea level value of barometric pressure typically reported by the airport and weather bureaus. It is sometimes referred to as the uncorrected barometric pressure (that is, not corrected to the mean sea level equivalent value). Refer to 5.5 for additional information.

3.1.16 *unit, n*—a single vacuum cleaner of the model being tested.

4. Significance and Use

4.1 The test results allow the comparison of the maximum potential air power available for cleaning tasks when tested under the conditions of this test method. The test results do not indicate the actual air power present during the cleaning process due to the effects of the various tools in use and surfaces being cleaned. During the nozzle on plenum chamber air performance testing, the brushroll is unloaded and this condition is not representative of the brushroll being in contact with carpet or other surfaces being cleaned.

5. Apparatus

5.1 *Plenum Chamber*—See Specification F 431 or IEC 60312, Section 5.2.8.2 (Figure 13c).

5.2 *Water Manometers*, or equivalent instruments. One to measure from 0 to 6 in. (152.4 mm) in increments of 0.01 in. (0.254 mm), and one with increments of 0.1 in. (2.54 mm) for use in making measurements above 6 in. (152.4 mm).

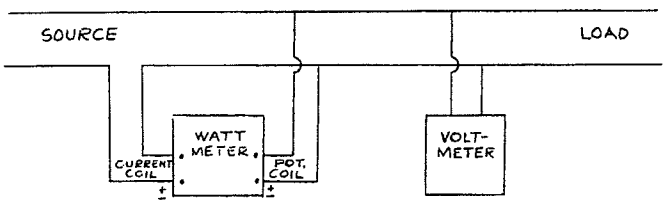


FIG. 1 Schematic Diagram of Meter Connections

5.3 *Wattmeter*, to provide measurements accurate to within ±1 %.

5.4 *Voltmeter*, to provide measurements accurate to within ±1 %.

5.5 *Barometer*, with an accuracy of ±0.05 in. of mercury (1.27 mm of mercury), capable of measuring and displaying absolute barometric pressure, scale divisions 0.02 in. (0.51 mm) or finer.

5.5.1 Mercury barometers, in general, measure and display the absolute barometric pressure. Some corrections may be needed for temperature and gravity. Consult the owner's manual.

5.5.2 When purchasing an aneroid or electronic barometer, be sure to purchase one which displays the absolute barometric pressure, not the mean sea level equivalent barometric pressure value. These types of barometers generally have temperature compensation built into them and do not need to be corrected for gravity.

5.6 *Sharp-Edge Orifice Plates*—See specifications in Specification F 431.

5.7 *Thermometer*— Solid-stem, ambient thermometer having a range from 18 to 89°F (or –8 to +32° C) with graduations in 0.2 F (0.1°C), conforming to the requirements for thermometer 63°F (17.2°C) as prescribed in Specification E 1.

5.8 *Psychrometer*—Thermometers graduated in 0.2 °F (0.1 °C).

5.9 *Voltage-Regulator System*, to control the input voltage to the vacuum cleaner. The regulator system shall be capable of maintaining the vacuum cleaner's rated voltage ±1 % and rated frequency having a wave form that is essentially sinusoidal with 3 % maximum harmonic distortion for the duration of the test.

6. Sampling

6.1 A minimum of three units of the same model vacuum cleaner, selected at random in accordance with good statistical practice, shall constitute the population sample.

6.1.1 To determine the best estimate of maximum air power for the population of the vacuum cleaner model being tested, the arithmetic mean of the maximum air power of the sample from the population shall be established by testing it to a 90 % confidence level within ±5 %.

6.1.2 Annex A2 provides a procedural example for determining the 90 % confidence level and when the sample size shall be increased (see Note 2).

NOTE 2—See Annex Annex A2 for method of determining 90 % confidence level.

7. Test Vacuum Cleaners

7.1 *New Test Vacuum Cleaners*:

7.1.1 *Preconditioning a New Test Vacuum Cleaner*—Run the vacuum cleaner in at rated voltage ±1 % and rated frequency with filters in place.

7.1.1.1 *Preconditioning a Rotating Agitator Type Vacuum Cleaner*—In a stationary position, operate the vacuum cleaner for 1 h with the agitator bristles not engaged on any surface.

7.1.1.2 *Preconditioning a Straight-Air Canister Vacuum Cleaner*—Operate the vacuum cleaner for 1 h with a wide-open inlet (without hose).

7.2 *Used Test Vacuum Cleaners*:

7.2.1 Recondition a used test vacuum cleaner; prior to the initial test run as follows:

7.2.1.1 Thoroughly remove excess dirt from the vacuum cleaner. Without using tools for disassembly, clean the entire outer surface, brushes, nozzle chamber, ductwork, inside of the chamber surrounding the primary filter, and inside hose and wands.

7.2.1.2 For vacuum cleaners using disposable filters as the primary filters, use a new disposable primary filter from the manufacturer for each test. Install it as recommended by the vacuum cleaner manufacturer.

7.2.1.3 For vacuum cleaners using water as the primary filter, empty the receptacle and refill as recommended by the manufacturer.

7.2.1.4 For vacuum cleaners using non-disposable dirt receptacles, empty in accordance with the manufacturer's instructions and clean the receptacle until its weight is within 0.07 oz (2 g) of its original weight and install it as recommended by the vacuum cleaner manufacturer.

NOTE 3—It is preferable to conduct this test method on new test vacuum cleaners prior to any other ASTM test methods to avoid contamination that could cause performance variations.

7.3 *Test Vacuum Cleaner Settings* —If various settings are provided, set the motor speed setting or suction regulator using the manufacturer's specifications as provided in the instruction manual for normal operation. If a different setting is used, make a note of the deviation in the test report.

8. Procedure

8.1 *Preparation for Test*:

8.1.1 Prepare the test vacuum cleaner(s) in accordance with Section 7.

8.1.2 Set the manometers to zero and check all instruments for proper operation.

8.1.3 Record the test station pressure and the dry-bulb and wet-bulb temperature readings within 6 ft of the test area. Read the barometric pressure to the nearest 0.02 in. of mercury (0.51 mm of mercury), and the dry-bulb and wet-bulb temperatures to the nearest 0.2 °F (or 0.1 °C)

8.1.3.1 The test area shall be free of major fluctuating temperature conditions due to air conditioners or air drafts that would be indicated by a thermometer at the immediate test area.

8.1.4 Connect a manometer or equivalent instrument to the plenum chamber.

8.1.5 Connect a wattmeter and a voltmeter in accordance with Fig. 1.

8.1.5.1 *Wattmeter Correction*—If needed, the indication may be corrected for voltmeter and wattmeter potential coil loss by opening the load circuit on the load side of the wattmeter with the line voltage at the operating value. The wattmeter current connection may be at its most sensitive position. Subtract this loss value from the total load indication to obtain the true load. As an alternative method, use the following equation:

$$W_c = W_i - V^2/R_T \quad (1)$$

where:

W_c = corrected wattage,
W_i = indicated wattage,
V = voltmeter reading, and
R_T = $R_P \times R_V/(R_P + R_V)$,

where:

R_T = total resistance, Ω,
R_P = wattmeter potential coil resistance, Ω, and
R_V = voltmeter coil resistance, Ω.

8.2 *Setup—Attachment Hose*:

8.2.1 Connect the hose assembly to the plenum chamber hose adapter and seal only this connection. See Fig. 2.

8.2.1.1 The end of the hose assembly should be inserted inside the hose connector adapter and be perpendicular to the plenum chamber.

8.2.1.2 The end of the hose assembly shall not project into the plenum chamber.

8.2.2 The hose should be supported and kept straight and horizontal. Maintain the vacuum cleaner in its normal operating orientation. If the hose is not intended to enter the vacuum cleaner horizontally, gradually bend the hose with a single bend from the intake port to the plenum chamber. Any restraining method should allow the hose coupling to seal at the cleaner. See Fig. 3.

8.3 *Test Setup—Carpet Cleaning Mode*:

8.3.1 Mount the cleaner plate as shown in Fig. 1e of Specification F 431 to the plenum chamber.

8.3.2 Make an adapter by any convenient method which adapts the test vacuum cleaner's nozzle opening to the opening in the cleaner plate.

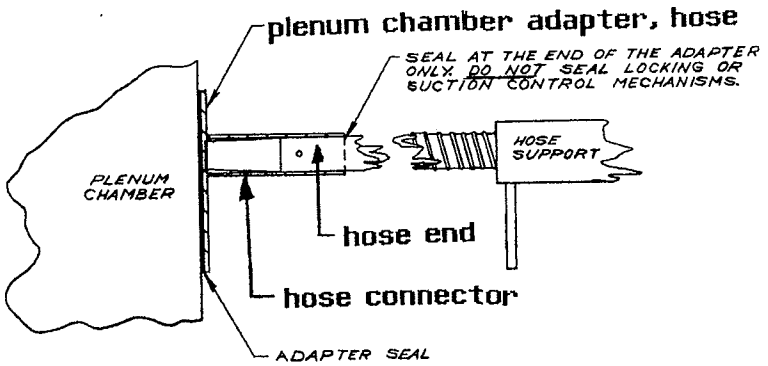


FIG. 2 Diagram of Hose and Adapter Connection

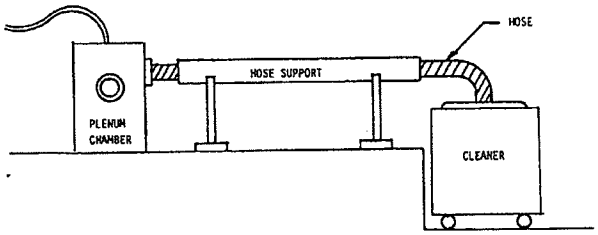


FIG. 3 Schematic for Air Performance Test

8.3.3 Maintain the largest cross-sectional area possible throughout the adapter. This will prevent impeding the airflow between the plenum chamber and the test vacuum cleaner's nozzle.

8.3.4 It is recommended that the hole for the adapter/plenum chamber interface be located as close, if not directly below, the dirt pickup duct for the test vacuum cleaner's nozzle.

8.3.5 The interface between the adapter and the test vacuum cleaner's nozzle is to be airtight. This may be achieved by an convenient means.

8.3.6 If the vacuum cleaner incorporates edge cleaning slots along the side edge(s), or slots along the front and rear edge of the bottom plate, or both, these slots should be sealed by any convenient means such as clay, tape, and so forth.

8.3.7 Do not eliminate leaks resulting from test vacuum cleaner's construction, except at the adapter/nozzle interface as described above.

8.3.8 An example of an adapter is shown in Fig. 4. This adapter uses a closed-cell foam gasket material or molded low durometer urethane material shaped to fit the contour of the test cleaner's nozzle opening with sufficient surface area for sealing.

8.3.9 Attach the nozzle adapter to the plenum chamber's cleaner plate, taking care to center the adapter's opening over the hole in the cleaner plate.

8.3.10 The interface between the adapter and the plenum chamber should be airtight. The use of foam, clay, tape, or any other convenient means may be used to make this interface airtight.

8.3.11 Mount the test vacuum cleaner to the nozzle adapter by any convenient means.

8.3.12 The test vacuum cleaner, when mounted to the plenum chamber, should be set on the plenum chamber/adapter in the user position. If needed, the test vacuum cleaner's rear wheels should be supported to keep the cleaner's foot parallel with the plenum chamber's surface.

8.3.13 For test cleaners incorporating a pivoting handle, support the test vacuum cleaner's handle at 31.5 in. above the nozzle/adapter surface.

8.3.14 For those vacuum cleaners which have a non-pivoting handle, support the test vacuum cleaner's handle at a height such that the cleaner's nozzle is parallel to the surface of the nozzle adapter.

8.3.15 Secure the test vacuum cleaner to the plenum chamber to prevent the test vacuum from possibly moving and breaking the airtight seal during the test.

8.4 *Test Procedure*:

8.4.1 Any automatic bleed valve which affects the air performance of the vacuum cleaner shall not be defeated.

8.4.2 Operate the vacuum cleaner with no orifice plate inserted in the plenum chamber inlet at nameplate rated voltage ±1 % and frequency ±1 Hz prior to the start of the test run to allow the unit to reach its normal operating temperature. For vacuum cleaners with dual nameplate voltage ratings, conduct testing at the highest voltage. Do this before each test run.

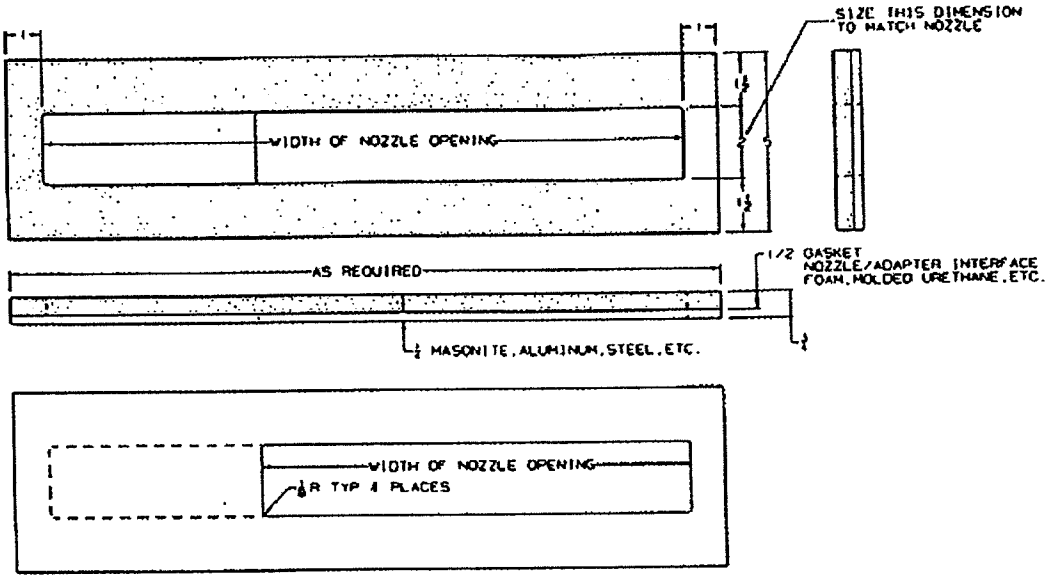


FIG. 4 Nozzle Adapter

8.4.3 The vacuum cleaner is to be operated at its nameplate rated voltage ±1 % and frequency ±1 Hz throughout the test. For vacuum cleaners with dual nameplate voltage ratings, conduct the test at the highest voltage.

8.4.3.1 Allow the vacuum cleaner to operate at the open orifice for 1 to 2 min between test runs.

8.4.4 While operating the vacuum cleaner per 8.4.3, insert orifice plates sequentially into the orifice plate holder of the plenum chamber starting with the largest size orifice and following it with the next smaller orifice plate. Use the following orifice plates: 2.000, 1.500, 1.250, 1.000, 0.875, 0.750, 0.625, 0.500, 0.375, 0.250, and 0 in. (50.8, 38.1, 31.7, 25.4, 22.2, 19.0, 15.8, 12.7, 9.5, and 6.3 mm). The following optional orifice plates may also be used: 2.500, 2.250, 1.750, 1.375, and 1.125 in. (63.5, 57.2, 44.5, 34.9, and 28.6 mm).

8.4.5 For each orifice plate, record the suction, h, and input power, P, in that order. All readings should be taken within 10 s of the orifice insertion. Allow the vacuum cleaner to operate at the open orifice for 1 to 2 min before inserting the next orifice.

8.4.5.1 Read the suction to the nearest graduation of the instrument. Readings should be taken as soon as the manometer reaches a true peak. (When using a fluid type manometer, the liquid level may peak, drop, and peak again. The second peak is the true peak reading. A person conducting the test for the first time shall observe at least one run before recording data. See Specification F 431 for instructions on how to minimize the overshoot (first peak) of the liquid level).

9. Calculation

9.1 *Correction of Data to Standard Conditions*:

9.1.1 *Air Density Ratio*—The density ratio, D_r, is the ratio of the air density at the time of test ρ_{test}, to the standard air density, ρ_{std}= 0.075 lb/ft^3 (1.2014 kg/m^3). It is used to correct the vacuum and wattage readings to standard conditions. Find ρ_{test} (lb/ft^3 or kg/m^3) from standard psychometric charts or ASHRAE tables and calculate D_r as follows:

$$D_r = \frac{\rho_{test}}{\rho_{std}} \quad (2)$$

where:

ρ_{test} = the air density at the time of test, lb/ft^3, and
ρ_{std} = the standard air density, 0.075 lb/ft^3.

9.1.1.1 As an alternative, the following equation is intended to be used for correcting ambient conditions where the barometric pressure exceeds 27 in mercury and the dry-bulb and wet-bulb temperatures are less than 100°F (37.8°C); and may be used as an alternate method of calculating D_r (see Appendix X1 for derivation and accuracy analysis).

$$D_r = \frac{[17.68\,B_t - 0.001978\,T_w^2 + 0.1064\,T_w + 0.0024575\,B_t(T_d - T_w) - 2.741]}{T_d + 459.7}$$

where:

B_t = test station pressure at time of test, in. of mercury,
T_d = dry-bulb temperature at time of test, °F, and
T_w = wet-bulb temperature at time of test, °F.

9.1.2 *Corrected Suction*—Corrected suction, h_s, is the manometer reading, h, times the correction factor, C_s as follows:

$$h_s = C_s h \quad (3)$$

9.1.2.1 For series universal motors (see Ref (6)) the correction factor, C_s, is calculated as follows:

$$C_s = 1 + 0.667\,(1 - D_r) \quad (4)$$

9.1.2.2 This test method does not have any formulas available for correcting input power for any other type of motor (permanent magnet, induction, etc.)

9.1.3 *Corrected Input Power*—Corrected input power, P_s, expressed in watts, is the wattmeter reading, P, times the correction factor, C_p, as follows:

$$P_s = C_p P \quad (5)$$

9.1.3.1 For series universal motors the correction factor, C_p, is calculated as follows:

$$C_p = 1 + 0.5(1 - D_r) \quad (6)$$

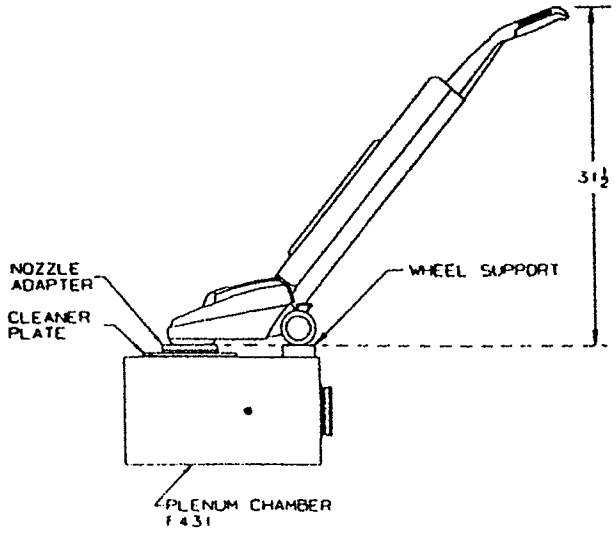


FIG. 5 Vacuum Cleaner Test Arrangement

9.1.3.2 This test method does not have any formulas available for correcting input power for any other types of motor (permanent magnet, induction, etc.)

9.2 *Corrected Airflow*—Calculate the corrected airflow, Q, expressed in cubic feet per minute (see Note 4 and Appendix X2) as follows:

$$Q = 21.844 D^2 K_1 \sqrt{h_s} \quad (7)$$

where:

Q = corrected flow, cfm,
D = orifice diameter, in.,
K_1 = constant (dimensionless), orifice flow coefficients for orifices in the plenum chamber. See Table 1 for values for each orifice. See Ref (1) for the derivation of these flow coefficients.
h_s = corrected suction, in. of water.

NOTE 4—For the corrected airflow expressed in liters per second, use the following equation:

$$Q = 10.309\, D^2 K_1 \sqrt{h_s}$$

TABLE 1 Orifice Flow Coefficient Equations (K_1)

NOTE 1—K_1 was determined experimentally using an ASTM plenum chamber (see Specification F 431) and an ASME flowmeter (see Ref (1)).
NOTE 2—Equations for K_1 in terms of B_t and h are given in Appendix X6.

Orifice Diameter, in. (mm)	Orifice Flow Coefficient Equation[A]
0.250 (6.3)	$K_1 = \frac{0.5575r - 0.5955}{r - 1.0468}$
0.375 (9.5)	$K_1 = \frac{0.5553r - 0.5754}{r - 1.0263}$
0.500 (12.7)	$K_1 = \frac{0.5694r - 0.5786}{r - 1.0138}$
0.625 (15.8)	$K_1 = \frac{0.5692r - 0.5767}{r - 1.0104}$
0.750 (19.0)	$K_1 = \frac{0.5715r - 0.5807}{r - 1.0138}$
0.875 (22.2)	$K_1 = \frac{0.5740r - 0.5841}{r - 1.0158}$
1.000 (25.4)	$K_1 = \frac{0.5687r - 0.5785}{r - 1.0146}$
1.125 (28.6)	$K_1 = \frac{0.5675r - 0.5819}{r - 1.0225}$
1.250 (31.7)	$K_1 = \frac{0.5717r - 0.5814}{r - 1.0152}$
1.375 (34.9)	$K_1 = \frac{0.5680r - 0.5826}{r - 1.0235}$
1.500 (38.1)	$K_1 = \frac{0.5719r - 0.5820}{r - 1.0165}$
1.750 (44.5)	$K_1 = \frac{0.5695r - 0.5839}{r - 1.0235}$
2.000 (50.8)	$K_1 = \frac{0.5757r - 0.5853}{r - 1.0157}$
2.250 (57.2)	$K_1 = \frac{0.5709r - 0.5878}{r - 1.0279}$
2.500 (63.5)	$K_1 = \frac{0.5660r - 0.59024}{r - 1.0400}$

[A]

$$r = \frac{B_t\,(0.4912) - h(0.03607)}{B_t\,(0.4912)}$$

where:

B_t = test station pressure at time of test, in. of mercury, and
h = uncorrected suction (manometer reading), in. of water.

TABLE 2 Repeatability and Reproducibility

Test Type	Coefficient of Variation, CV %$_r$	Repeatability Limit, r	Coefficient of Variation, CV %$_R$	Reproducibility Limit, R
End of Hose	2.190	6.132	6.533	18.292
Nozzle	4.795	13.426	19.265	53.942

where:

Q = corrected flow, L/s,
D = orifice diameter, m,
K_1 = constant (dimensionless), and
h_s = corrected suction, Pa.

9.3 *Air Power*—Calculate the air power, AP, in watts, as follows:

$$AP = 0.117354\,(Q)(h_s) \quad (8)$$

where:

AP = air power, W,
Q = corrected flow, cfm, and
h_s = corrected suction, inch of water.

NOTE 5—See Appendix X3 for derivation.

9.4 *Maximum Air Power*—Determine the maximum air power using the method in Annex A1.

10. Report

10.1 For each vacuum cleaner sample from the population being tested, report the following information:

10.1.1 Manufacturer's name and product model name or number, or both.

10.1.2 Type of cleaner; that is, upright, canister, etc.

10.1.3 The corrected input power, corrected vacuum, corrected airflow, and air power for each orifice used.

10.1.4 Calculated maximum air power.

10.1.5 Indicate the method of testing, end of hose or nozzle on plenum.

11. Precision and Bias [6]

11.1 The following precision statements are based on interlaboratory tests involving eight laboratories and four units.

11.2 The statistics have been calculated as recommended in Practice E 691.

11.3 The following statements regarding repeatability limit and reproducibility limit are used as directed in Practice E 177.

11.4 The End of Hose Coefficients of Variation of repeatability and reproducibility of the measured results have been derived from nine sets of data, where each of two sets have been performed by a single analyst within each of the eight laboratories on separate days using the same test unit.[6]

11.5 The Nozzle Coefficients of Variation of repeatability and reproducibility of the measured results have been derived from seven sets of data, where each of two sets have been performed by a single analyst within each of the seven laboratories on separate days using the same test unit.[6]

[6] Complete data on the round-robin test is available from ASTM Headquarters. Request RR:F11-1010.

11.6 *Repeatability (Single Operator and Laboratory, Multiday Testing)*—The ability of a single analyst to repeat the test within a single laboratory.

11.6.1 The expected coefficient of variation of the measured results within a laboratory, CV $\%_r$, has been found to be the respective values listed in Table 2.

11.6.2 The 95 % repeatability limit within a laboratory, r, has been found to be the respective values listed in Table 2, where $r = 2.8$ (CV $\%_r$).

11.6.3 With 95 % confidence, it can be stated that within a laboratory a set of measured results derived from testing a unit should be considered suspect if the difference between any two of the three values is greater than the respective value of the repeatability limit, r, listed in Table 2.

11.6.4 If the absolute value of the difference of any pair of measured results from three test runs performed within a single laboratory is not equal to or less than the respective repeatability limit listed in Table 2, that set of results shall be considered suspect.

11.7 *Reproducibility (Multiday Testing and Single Operator Within Multilaboratories)*—The ability to repeat the test within multiple laboratories.

11.7.1 The expected coefficient of variation of reproducibility of the average of a set of measured results between multiple laboratories, CV $\%_R$, has been found to be the respective values listed in Table 2.

11.7.2 The 95 % reproducibility limit within a laboratory, R, has been found to be the respective values listed in Table 2, where $R = 2.8$ (CV $\%_R$).

11.7.3 With 95 % confidence, it can be stated that the average of the measured results from a set of three test runs performed in one laboratory, as compared to a second laboratory, should be considered suspect if the difference between those two values is greater than the respective values of the reproducibility limit, R, listed in Table 2.

11.7.4 If the absolute value of the difference between the average of the measured results from the two laboratories is not equal to or less than the respective reproducibility limit listed in Table 2, the set of results from both laboratories shall be considered suspect.

11.8 *Bias*—No justifiable statement can be made on the accuracy of this test method for testing the properties listed. The true values of the properties cannot be established by acceptable referee methods.

12. Keywords

12.1 airflow; air performance; air power; suction; suction power; vacuum cleaner

ANNEXES

(Mandatory Information)

A1. MATHEMATICAL METHOD FOR DETERMINING MAXIMUM AIR POWER POINT

A1.1 The following, second degree polynomial equation, is assumed to provide the best mathematical approximation of the air power versus airflow relationship.

NOTE A1.1—See Ref (4) for additional information.

$$Y = A_1 + A_2X + A_3X^2 \quad \text{(A1.1)}$$

where:

Y = air power (AP),
X = airflow (Q), and
A_1, A_2, and A_3, = arbitrary constants.

A1.1.1 Use X and Y values obtained from only five specific orifices selected as follows:

A1.1.1.1 Using the test data, determine the orifice size that produced the highest air power value.

A1.1.1.2 Use the air power and airflow values at this orifice, and the next two smaller and the next two larger orifices in the following computations:

A1.1.1.3 If the highest air power value calculated from the observed data is at the 2.0 in. (50.8 mm) orifice or larger, then use the air power and airflow values from the five largest orifices.

A1.2 To determine the values of A_1, A_2, and A_3, use the X and Y values obtained from the five specified orifices and solve the following set of normalized equations:

$$\Sigma Y_i = NA_1 + A_2 \Sigma X_i + A_3 \Sigma X_i^2 \quad \text{(A1.2)}$$

$$\Sigma X_iY_i = A_1 \Sigma X_i + A_2 \Sigma X_i^2 + A_3 \Sigma X_i^3 \quad \text{(A1.3)}$$

$$\Sigma X_i^2Y_i = A_1 \Sigma X_i^2 + A_2 \Sigma X_i^3 + A_3 \Sigma X_i^4 \quad \text{(A1.4)}$$

where:

N = 5 (number of orifices selected),
i = 1 to N, and
X_i and Y_i = the values obtained during testing (X_1Y_1, X_2Y_2, . . . X_NY_N) at the five orifices specified in A1.1.1.

A1.3 Setting the derivative of Eq A1.1 equal to zero and solving for X will determine the value of X_m where Y is at its maximum value f(Y_{max}) as follows:

$$\frac{dy}{dx} = \frac{d}{dx}[A_1 + A_2X + A_3X^2] = 0 \quad \text{(A1.5)}$$

$$\frac{dy}{dx} = A_2 + 2A_3X = 0$$

Substitute X_m as the value of X at Y_{max} and solve for X_m:

$$X_m = -\frac{A_2}{2A_3} \quad \text{(A1.6)}$$

Substituting this value of X_m, and A_1, A_2, and A_3, into Eq 1 will determine the value of Y_{max} (AP_{max}) as follows:

$$Y_{max} = A_1 + A_2X_m + A_3X_m^2 \quad \text{(A1.7)}$$

A1.4 Calculate the goodness of fit, R (correlation coefficient) as follows:

$$R = 1 - \frac{\Sigma (Y_{i\,OBS} - Y_{i\,CAL})^2}{\Sigma (Y_{i\,OBS} - Y_{OBS})^2} \quad \text{(A1.8)}$$

where:

$$Y_{i\,CAL} = A_1 + A_2X_{i\,OBS} + A_3X^2_{i\,OBS} \quad \text{(A1.9)}$$

and:

$$Y_{OBS} = \frac{1}{N}\Sigma Y_{i\,OBS} \quad \text{(A1.10)}$$

and:

i = 1 to N orifices used in 8.2,
OBS = observed data,
CAL = calculated data, and
$Y_{i\,OBS}$ = is the air power (AP) obtained from the calculations in 9.3 for the corresponding value $X_{i\,OBS}$ (airflow, Q) at any of the N orifices selected.

A1.4.1 If R is not greater than or equal to 0.900, the test must be performed again and the new set of data shall be used.

A2. DETERMINATION OF 90 % CONFIDENCE INTERVAL

A2.1 *Theory*:

A2.1.1 The most common and ordinarily the best estimate of the population mean, μ, is simply the arithmetic mean, $\bar{x}$, of the individual scores (measurements) of the units comprising a sample taken from the population. The average score of these units will seldom be exactly the same as the population mean; however, it is expected to be fairly close so that in using the following procedure it can be stated with 90 % confidence that the true mean of the population, μ, lies within 5 % of the calculated mean, $\bar{x}$, of the sample taken from the population as stated in Section 6.

A2.1.2 The following procedure provides a confidence interval about the sample mean which is expected to bracket μ, the true population mean, 100(1-α) % of the time where α is the chance of being wrong. Therefore, 1-α is the probability or level of confidence of being correct.

A2.1.3 The desired level of confidence is 1-α = 0.90 or 90 % as stated in Section 11. Therefore α = 0.10 or 10 %.

A2.1.4 Compute the mean, $\bar{x}$, and the standard deviation, s, of the individual scores of the sample taken from the population:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} X_i \quad \text{(A2.1)}$$

$$s = \sqrt{\frac{n\sum_{i=1}^{n} X_i^2 - (\sum_{i=1}^{n} X_i)^2}{n(n-1)}} \quad \text{(A2.2)}$$

where:

n = number of units tested, and
X_i = the value of the individual test unit score of the ith test unit. As will be seen in the procedural example to follow, this is the average value of the results from three test runs performed on an individual test unit with the resulting set of data meeting the repeatability requirements of Section 11.

A2.1.5 Determine the value of the t statistic for n – 1 degrees of freedom, df, from Table A2.1 at a 95 % confidence level.

NOTE A2.1—The value of t is defined as $t_{1-\alpha/2}$ and is read as "t at 95 % confidence."

$$t \text{ statistic} = t_{1-\alpha/2} = t_{0.95} \quad \text{(A2.3)}$$

TABLE A2.1 Percentiles of the *t* Distribution

df	$t_{0.95}$
1	6.314
2	2.920
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.860
9	1.833
10	1.812
11	1.796
12	1.782
13	1.771
14	1.761
15	1.753

where:
1-α/2 = 1 – 0.10/2 = 1 – 0.05 = 0.95, or 95 %.

A2.1.6 The following equations establish the upper and lower limits of an interval centered about $\bar{x}$ that will provide the level of confidence required to assert that the true population mean lies within this interval:

$$CI_U = \bar{x} + ts/\sqrt{n} \quad \text{(A2.4)}$$

$$CI_L = \bar{x} - ts/\sqrt{n} \quad \text{(A2.5)}$$

where:

CI = Confidence Interval (U - upper limit; L - lower limit),
$\bar{x}$ = mean score of the sample taken from the population,
t = t statistic from Table A2.1 at 95 % confidence level,
s = standard deviation of the sample taken from the population, and
n = number of units tested.

A2.1.7 It is desired to assert with 90 % confidence that the true population mean, μ, lies within the interval, CI_U to CI_L, centered about the sample mean, $\bar{x}$. Therefore, the quantity $ts/\sqrt{n}$ shall be less than some value, A, which shall be 5 % of $\bar{x}$ in accordance with the sampling statement of 6.1.

A2.1.8 As $n \to \infty$, $ts/\sqrt{n} \to 0$. As this relationship indicates, a numerically smaller confidence interval may be obtained by using a larger number of test units, n, for the sample. Therefore, when the standard deviation, s, of the sample is large and the level of confidence is not reached after testing three units, a larger sample size, n, shall be used.

A2.2 *Procedure*—A graphical flow chart for the following procedure is shown in Fig. A2.1.

A2.2.1 Select three units from the population for testing as the minimum sample size.

A2.2.2 Obtain individual test unit scores by averaging the results of three test runs performed on each of the three individual test units. The data set resulting from the three test runs performed on each individual test unit shall meet the respective repeatability requirement found in Section 11.

A2.2.3 Compute $\bar{x}$ and s of the sample.

A2.2.4 Compute the value of A where $A = 0.05(X)$

A2.2.5 Determine the statistic t for $n - 1$ degrees of freedom from Table A2.1 where n = the number of test units.

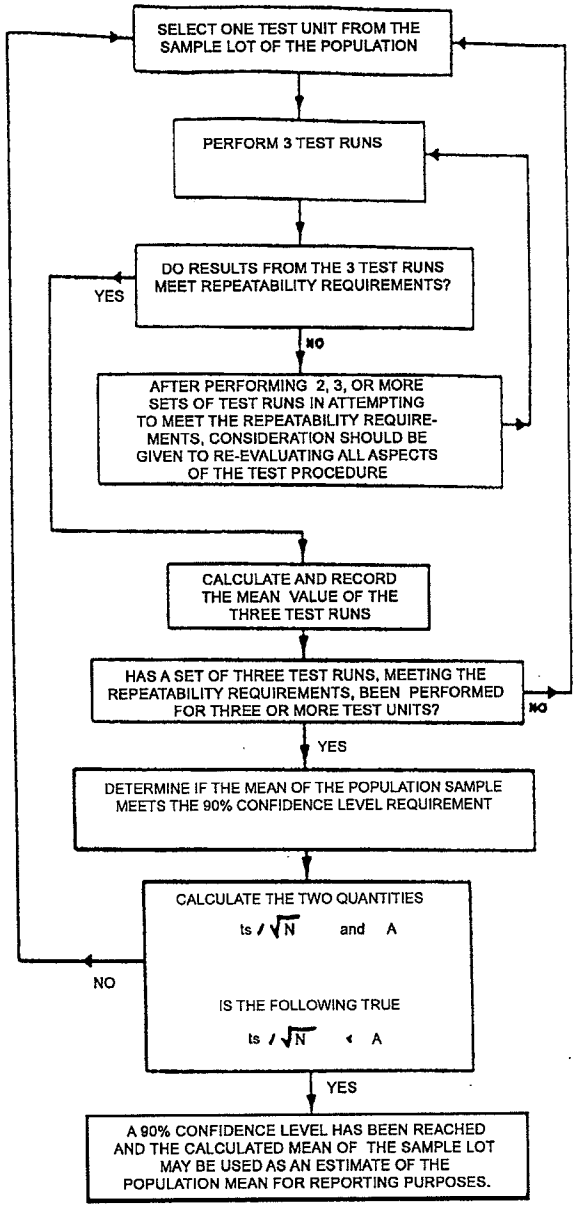


FIG. A2.1 Testing Procedure Flowchart

A2.2.6 Compute $ts/\sqrt{n}$ for the sample and compare it to the value to A.

A2.2.7 If the value of $ts/\sqrt{n} > A$, an additional unit from the population shall be selected and tested, and the computations of steps A2.2.2-A2.2.6 repeated.

A2.2.8 If the value of $ts/\sqrt{n} < A$, the desired 90 % confidence level has been obtained. The value of the final $\bar{x}$ may be used as the best estimate of the air power rating for the population.

A2.3 *Example*—The following data is chosen to illustrate how the attachment hose value of air power for the population of a vacuum cleaner model is derived. The measured test results from three test runs on each unit are required to have a repeatability limit not exceeding 6.132 as indicated in Section 11.

A2.3.1 Select three test units from the vacuum cleaner model population. A minimum of three test runs shall be performed using each test unit.

A2.3.2 Test run scores for Test Unit No. 1:

Test Run No. 1 = 77.4
Test Run No. 2 = 83.4
Test Run No. 3 = 82.1

A2.3.3 Maximum spread = 83.4 – 77.4 = 6

$$\% \text{ difference} = \text{maximum spread/maximum score} = \frac{6}{83.4} = 7.2\ \% \quad \text{(A2.6)}$$

This value is greater than the repeatability limit required in Section 11. The results shall be discarded and three additional test runs performed.

A2.3.4 Test runs scores for Test Unit No. 1:

Test Run No. 4 = 82.4
Test Run No. 5 = 80.9
Test Run No. 6 = 81.8

A2.3.5 Maximum spread = 82.4 – 80.9 = 1.5

$$\% \text{ difference} = \text{maximum spread/maximum score} = \frac{1.5}{82.4} = 1.8\ \% \quad \text{(A2.7)}$$

This value is less than the repeatability limit requirement of Section 11.

A2.3.6 Unit No. 1 score = (82.4 + 80.9 + 81.8)/3 = 81.7

NOTE A2.2—If it is necessary to continue repeated test run sets (7, 8, 9, 10, 11, 12, etc.) because the spread of data within a data set is not less than the repeatability limit requirement stated in Section 11, there may be a problem with the test equipment, the execution of the test procedure, or any of the other factors involved in the test procedure. Consideration should be given to re-evaluating all aspects of the test procedure for the cause(s).

A2.3.7 A minimum of two additional test units must be tested, each meeting the repeatability limit requirement. For this procedural example, assume those units met the repeatability requirement and the individual unit scores are:

Score of Test Unit No. 1 = 81.7
Score of Test Unit No. 2 = 88.3
Score of Test Unit No. 3 = 86.6

A2.3.8

$$\bar{x} = 1 / 3\,(81.7 + 88.3 + 86.6) = 85.5 \quad \text{(A2.8)}$$

A2.3.9

$$s = \sqrt{\frac{3[(81.7)^2 + (88.3)^2 + (86.6)^2] - [81.7 + 88.3 + 86.6]^2}{3\,(3-1)}} \quad \text{(A2.9)}$$

where:
s = 3.426.

A2.3.10

$$A = 0.05\,(85.5) = 4.276 \quad \text{(A2.10)}$$

A2.3.11

$$\text{degrees of freedom, } n - 1 = 3 - 1 = 2 \quad \text{(A2.11)}$$

$$t_{0.95} \text{ statistic} = 2.920$$

A2.3.12

$$ts/\sqrt{n} = 2.920\,(3.426)/\sqrt{3} = 5.777 \quad \text{(A2.12)}$$

A2.3.13 Since 5.777 > 4.276, the requirement that $ts/\sqrt{n} < A$ has not been met because s is large. Therefore, an additional test unit from the population shall be tested.

A2.3.14 Score of Test Unit No. 4 = 84.5.

A2.3.15

$$\bar{x} = 1/4\,(81.7 + 88.3 + 86.6 + 84.5) = 85.3 \quad \text{(A2.13)}$$

A2.3.16

$$s = \sqrt{\frac{4[(81.7)^2 + (88.3)^2 + (86.6)^2 + (84.5)^2] - [81.7 + 88.3 + 86.6 + 84.5]^2}{4\,(4-1)}} \quad \text{(A2.14)}$$

where:
s = 2.845.

A2.3.17

$$A = 0.05\,(85.3) = 4.264 \quad \text{(A2.15)}$$

A2.3.18

$$\text{degrees of freedom, } n - 1 = 4 - 1 = 3 \quad \text{(A2.16)}$$

$$t_{0.95} \text{ statistic} = 2.353$$

A2.3.19

$$ts/\sqrt{n} = 2.353\,(2.845)/\sqrt{4} = 3.347 \quad \text{(A2.17)}$$

A2.3.20 3.347 < 4.264 (meets requirements)

A2.3.21 Thus, the value of $\bar{x}$, 85.3, represents the air power score for the vacuum cleaner model tested and may be used as the best estimate of the air power rating for the population mean.

APPENDIXES

(Nonmandatory Information)

X1. DERIVATION OF DENSITY RATIO FORMULA

X1.1 Symbols

- D_r = density ratio, which is the air density at time of test divided by the standard density, dimensionless,
- R = gas constant, = 1545/MW, ft/°R,
- MW_a = molecular weight of dry air = 28.9644,
- Mw_v = molecular weight of water vapor = 18.016 or 0.622 MW_a,
- V = specific volume of fluid = 1/[ρ], lb/ft^3,
- ρ_{std} = standard air density = 0.075 lb/ft^3,
- ρ_{test} = density of moisture-laden air, lb/ft^3,
- ρ_a = density of dry air portion of moisture-laden air, lb/ft^3,
- ρ_v = density of water vapor portion of moisture laden air, lb/ft^3,
- ρ_m = density of mercury at 32°F = 848.713 lb/ft^3,
- P = absolute pressure of gas, lb/ft^2,
- b = absolute pressure of gas, in. of mercury,
- B_t = test station pressure at time of test, in. of mercury,
- T = absolute temperature,° R,
- T_d = dry-bulb temperature,° F,
- T_w = wet-bulb temperature,° F,
- svp = saturated vapor pressure at wet-bulb temperature, inch of mercury, and
- e = partial vapor pressure at test condition, in. of mercury.

X1.2 Derivation

NOTE X1.1—See AMCA Standard 210-85.

$PV = RT$ and $V = 1/\rho$, therefore
$P/\rho = RT$ or $\rho = P/RT$

X1.2.1 Conversion of P to b:

$$P = \rho_m(b/12) = (848.713/12)b = 70.7261b \quad \text{(X1.1)}$$

X1.2.2 ρ_a Calculation:

$$R = \frac{1545}{MW_a} = \frac{1545}{28.9644} \quad \text{(X1.2)}$$

$$\rho_a = \frac{P}{RT} = \frac{70.7261b}{53.34(T_d + 459.7)}$$

$$b \text{ (dry air portion)} = (B_t - e)$$

$$\rho_a = \frac{70.7261}{53.34} \times \frac{B_t - e}{(T_d + 459.7)}$$

X1.2.3 ρ_v Calculation:

$$R = \frac{1545}{MW_v} = \frac{1545}{0.622(MW_a)} = \frac{53.34}{0.622} \quad \text{(X1.3)}$$

$$b \text{ (water vapor portion)} = e$$

$$\rho_v = \frac{70.7261}{53.34} \times \frac{0.622e}{(T_d + 459.7)}$$

X1.2.4 ρ_{test} Calculation:

$$\rho_{test} = \rho_a + \rho_v \quad \text{(X1.4)}$$

$$= \frac{70.7261}{53.34} \times \left(\frac{(B_t - e) + 0.622\, e}{T_d + 459.7} \right)$$

$$= \frac{1.32595\,(B_t - 0.378\, e)}{T_d + 459.7}$$

X1.2.5

$$D_r = \frac{\rho_{test}}{\rho_{std}} = \frac{\rho_{test}}{0.075} \qquad \text{(X1.5)}$$

$$= \frac{17.68\,(B_t - 0.378\, e)}{T_d + 459.7}$$

X1.2.6

$$e = svp - B_t \frac{(T_d - T_w)}{2700} \qquad \text{(X1.6)}$$

X1.2.7

$$svp = 2.959910^{-4}\, T_w^{\,2} - 1.5927{\cdot}10^{-2}\, T_w + 4.102\,(10^{-1}). \qquad \text{(X1.7)}$$

X1.2.8 Combining the equations in X1.2.5, X1.2.6, and X1.2.7:

$$D_r = [17.68B_t - 0.001978T_w^{\,2} + 0.1064\, T_w + 0.0024575\, B_t\, (T_d - T_w) - 2.741]/(T_d + 459.7) \qquad \text{(X1.8)}$$

X1.3 Error Analysis for Usable Range of *svp* Equation

NOTE X1.2—See error analysis for usable range in AMCA Standard 210-85.

COMPUTATION METHODS FOR SVP COMPARISON

X1.3.1 The *svp* equation is taken from AMCA Standard 210-85 and used in X1.2 versus *svp* value tabulations in Ref (2).

ANALYSIS

X1.3.2 *Probability of Error in svp*:

X1.3.2.1 The plot of data shows very little error at 80°F (26.7°C) and below but increasingly larger error as T_w increases above 80°F.

EFFECT ON SVP ERROR ON CALCULATION OF E (X1.2.6)

X1.3.3 The worst error is when $T_d = T_w$ (that is, 100 % relative humidity). At that point the "e" error = *svp* error. Error in "e" reduces with decreasing humidity.

EFFECT OF ERROR IN *SVP* ON CALCULATION OF D_r (X1.2.5)

X1.3.4 The $B - 0.378e$ factor greatly reduces any error in "e" (or *svp*) since B is far greater in magnitude than $0.378e$.

X1.3.4.1 The worst-error case is with lowest "B" and highest "e."

CONCLUSION

X1.3.5 The worst-error condition is with low barometric condition, high wet-bulb temperature, and 100 % relative humidity.

X1.3.6 If the D_r equation is restricted to minimum value of B = 27.00 in. of mercury absolute and maximum value of T_w = 100°F (37.8°C) then at the worst-case condition of 100 % relative humidity the D_r error = +0, –0.23 %.

X2. DERIVATION OF AIR FLOW FORMULA FROM ASME STANDARDS

X2.1 From Ref (3), p. 54, eq. (1-5-36):

$$Q_1 = 0.099702 \frac{(CYd^2F_a)}{(\sqrt{1-\beta^4})} \sqrt{\frac{h_s}{\rho_{std}}} \qquad \text{(X2.1)}$$

where:

- Q_1 = flow rate at standard, air density and temperature, ft^3/s,
- C = coefficient of discharge, dimensionless,
- Y = expansion factor, dimensionless,
- F_a = thermal expansion factor, dimensionless,
- β = d/D, dimensionless,
- d = orifice diameter, in.,
- D = diameter of pipe upstream, in.,
- h_s = differential pressure at standard conditions in. H_2O, and
- ρ_{std} = air density at standard conditions, 0.075 lb/ft^3.

X2.1.1 This equation determines the rate of gas flow in a pipe system, and measured with a venturi tube, a flow nozzle, or an orifice plate measuring device mounted in the pipe.

X2.1.2 The equation (1-5-36) from Ref (3), page 54, uses the symbol ρ_1 instead of ρ_{std} for the air density at standard conditions, q_1 instead of Q_1 for flow rate at standard air density and temperature, and h_s instead of h_w for differential pressure at standard conditions. The symbols ρ_1, q_1, and h_w were changed to ρ_{std}, Q_1 and h_s respectively as a matter of consistency within this standard and clarity. ($\rho_1 = \rho_{std}$, $h_s = h_w$, $Q_1 = q_1$).

X2.2 Converting to ft^3/min flow rate, substituting 0.075 for the value of ρ_{std} substituting K for $CF_a/\sqrt{1-B^4}$ and simplifying:

$$Q = 21.844KYd^2\sqrt{h_s} \qquad \text{(X2.2)}$$

where:

- Q = flow rate at standard, air density and temperature, cfm,
- K = orifice flow coefficient, dimensionless,
- d = orifice diameter, in., and
- h_s = differential pressure at standard conditions, in. of water.

X2.3 The ASTM plenum chamber, as specified in Specification F 431, is not a measuring device that uses a pipe. The flow from ambient into the sharp edged orifice plate is unrestricted and a plenum chamber is placed immediately, downstream of the orifice plate.

X2.3.1 Thus the orifice flow coefficient, K, and the expansion factor, of X2.2 are different for the plenum chamber specified in Specification F 431.

X2.3.2 For the plenum chamber specified in Specification F 431, the combination of the orifice flow coefficient K, and the expansion factor, Y, were empirically determined as a singular, orifice flow coefficient K_1.

X2.3.3 The value of K_1 will vary for each of the orifice plates identified in Section 9.

X2.4 Replacing K and Y in the equation of X2.2 with K_1 results in:

$$Q = 21.844\, K_1 d^2 \sqrt{h_s} \qquad \text{(X2.3)}$$

where:
Q = flow rate at standard, air density and temperature, cfm,
K_1 = orifice flow coefficient for the Specification F 431 plenum chamber, dimensionless,
d = orifice diameter, in., and
h_s = differential pressure at standard conditions, in. of water.

X2.4.1 This equation determines the rate of gas flow, in ft^3/min through a thin plate square edged orifice, mounted in accordance with Specification F 431.

X3. DERIVATION OF AIR POWER EQUATION

X3.1 Power is defined as the rate of doing work in a given period of time and can be expressed by the following general equation:

$$P = Fv \qquad \text{(X3.1)}$$

where:
P = power,
F = force, and
v = velocity.

X3.2 Air power as defined in the terminology section (see 3.1.1) is the net time rate of work performed by an air stream while expending energy to produce air flow by a vacuum cleaner under specified air resistance conditions, expressed in watts. Therefore air power is:

$$AP = 745.7/33000\, Fv \qquad \text{(X3.2)}$$

where:
AP = air power, W,
F = force generated by the air stream passing through the orifice, lbs, and
v = velocity, ft/min.

X3.2.1 The constant 745.7/33000 is used to maintain the correct set of units.

$$1 \text{ watt} = \frac{33000 \text{ ft lb}}{745.7 \text{ min}} \qquad \text{(X3.3)}$$

X3.3 For an air stream passing through a given orifice size:

X3.3.1 The force is given by the following equation:

$$F = \frac{1}{12} p\, h_s A \qquad \text{(X3.4)}$$

where:
F = force generated by air stream passing through the orifice, lbs,
p = density of water at (68°F), 62.3205 lb/ft^3,
h_s = differential pressure at standard conditions, in. of water, and
A = cross sectional area of the orifice, ft^2.

X3.3.1.1 The constant 1/12 is used to maintain the correct set of units

$$F \text{ (lbs)} = \frac{1}{12}\frac{\text{(ft)}}{\text{(in.)}}\, p\, \frac{\text{(lb)}}{\text{(ft}^3\text{)}}\, h_s \text{ (in.)}\, A \text{ (ft}^2\text{)} \qquad \text{(X3.5)}$$

X3.3.2 The velocity is given by the following equation:

$$V = Q/A \qquad \text{(X3.6)}$$

where:
V = velocity of air stream passing through the orifice, ft/min,
Q = flow rate at standard, air density and temperature, cfm, and
A = cross sectional area of the orifice, ft^2.

X3.4 Substituting equations from X3.3.1 and X3.3.2 into the equation of X3.2, p = 62.3205 lb/ft^3, and simplifying;

$$AP = 0.117354\, h_s Q \qquad \text{(X3.7)}$$

where:
AP = air power, W,
h_s = differential pressure at standard conditions, in. of water, and
Q = flow rate at standard air density and temperature, cfm.

X3.4.1 This is the equation used to calculate the air power in 9.3.

X4. STANDARD CONDITIONS

X4.1 Dry-bulb temperature, T_D = 68°F.

X4.2 Atmospheric pressure = 14.69595 psi.

X4.3 Relative humidity (approximate) = 30 %.

X4.4 Density of mercury at 32°F (Note X4.1), (ρH_s) = 848.71312 lb/ft^3.

X4.5 Density of water at 68°F, (ρ_{water}) = 62.3205 lb/ft^3

X4.6 Density of air at 68°F, 30 % relative humidity, ρ_0 = 0.075 lb/ft^3.

X4.7 Barometer reading, $B_0 = \rho_0/\rho\ Hg/(12)^3$ = 14.69595 (1728)/848.71312 = 29.9213 in. Hg at 32°F (Note X4.1).

X4.8 Water column height = $\rho_0/\rho_{water}/(12)^3$ = 14.69595

(1728)/62.3205 = 407.4829 in. H_2O at 68°F.

X4.9 To convert inches of mercury at 32°F to pounds force per square inch, multiply by 14.69595/29.921 = 0.491153 (use 0.4912).

X4.10 To convert inches of water at 68°F to pounds force per square inch, multiply by 14.69595/407.4839 = 0.03606511 (use 0.03607).

NOTE X4.1—Mercury barometer readings are to be corrected to 32°F. See Kent's Mechanical Engineers Handbook.

X4.11 All constants are from AMCA Standard 210-85 and Refs (3) and (4).

X5. MINIMUM AND MAXIMUM *h* VALUES BY ORIFICE SIZE

Orifice Diameter, in. (mm)	Manometer Reading, h, in. H_2O	
	min	max
0.250 (6.3)	0.1	109
0.375 (9.5)	0.1	100
0.500 (12.7)	0.1	91
0.625 (15.8)	0.1	81
0.750 (19)	0.1	72
0.875 (22.2)	0.1	63
1.000 (25.4)	0.1	55
1.250 (31.7)	0.1	40
1.500 (38.1)	0.1	26
2.000 (50.8)	0.1	11

X6. ALTERNATE EQUATIONS FOR FINDING ORIFICE FLOW COEFFICIENT

NOTE X6.1—These equations are the results of substituting the *r* equation into the Table 1, K_1, equations.

Orifice Diameter, in. (mm)	Flow Coefficient	Orifice Diameter, in. (mm)	Flow Coefficient
0.250 (6.3)	$K_1 = \frac{0.020109h + 0.018665B_t}{0.03607h + 0.022988B_t}$	1.250 (31.7)	$K_1 = \frac{0.020621h + 0.004764B_t}{0.03607h + 0.007466B_t}$
0.375 (9.5)	$K_1 = \frac{0.020029h + 0.009873B_t}{0.03607h + 0.012918B_t}$	1.375 (34.9)	$K_1 = \frac{0.020488h + 0.007172B_t}{0.03607h + 0.011543B_t}$
0.500 (12.7)	$K_1 = \frac{0.0205382h + 0.004519B_t}{0.03607h + 0.00678B_t}$	1.500 (38.1)	$K_1 = \frac{0.020628h + 0.004961B_t}{0.03607h + 0.008104B_t}$
0.625 (15.8)	$K_1 = \frac{0.020531h + 0.003684B_t}{0.03607h + 0.005108B_t}$	1.750 (44.5)	$K_1 = \frac{0.020542h + 0.007073B_t}{0.03607h + 0.011543B_t}$
0.750 (19)	$K_1 = \frac{0.020614h + 0.004519B_t}{0.03607h + 0.006778B_t}$	2.000 (50.8)	$K_1 = \frac{0.020765h + 0.004715B_t}{0.03607h + 0.0077118B_t}$
0.875 (22.2)	$K_1 = \frac{0.020704h + 0.004961B_t}{0.03607h + 0.0077609B_t}$	2.250 (57.2)	$K_1 = \frac{0.020592h + 0.008301B_t}{0.03607h + 0.013704B_t}$
1.000 (25.4)	$K_1 = \frac{0.020513h + 0.004813B_t}{0.03607h + 0.00717152B_t}$	2.500 (63.5)	$K_1 = \frac{0.020416h + 0.011907B_t}{0.03607h + 0.019648B_t}$
1.125 (28.6)	$K_1 = \frac{0.020470h + 0.007073B_t}{0.03607h + 0.011052B_t}$		

X7. EXAMPLE OF CALCULATING AIR POWER AT TWO DIFFERENT TEST LOCATIONS

X7.1 This example shows the calculations of air density for two different test locations at two different elevations and the results of the maximum air power calculations.

X7.2 This example attempts to show the importance of using the test station pressure or absolute barometric pressure in the calculations of the air density instead of the equivalent mean sea level value of the absolute barometric pressure.

X7.2.1 Air density or the weight of the air per unit volume at a particular test location is influenced by the local weather conditions, the test locations height above sea level, the heating, cooling and ventilation system of the test facility, etc.

X7.2.1.1 In general, air density decreases as the elevation increases. The amount of the atmosphere above the test location decreases as elevation increases; thus the weight of the air above the test location decreases resulting in a lower air density.

X7.2.1.2 Air density is effected by the amount of moisture within the air. Water vapor adds weight to the air.

X7.3 For this example, a vacuum cleaner having the characteristics shown in Table X7.1 at standard air density conditions in accordance with 3.1.4 shall be used.

X7.3.1 The calculated maximum air power for this unit is 152 air watts.

X7.3.2 It will be assumed that this cleaner performs perfectly each time it is used (that is, no motor performance variations, the hose is laid out the exact same way for each test etc.)

TEST LOCATION 1: LOW ELEVATION

X7.4 In Harrisburg, PA, an independent test laboratory located 355 ft above sea level measured the maximum air power of the vacuum cleaner described in X7.3 per Specification F 558. At the test location and test time, the laboratory measured the test station pressure, B_t, the wet bulb temperature, T_w, and the dry bulb temperature, T_d. Their values were recorded as follows:

$$B_t = 29.10 \text{ in. Hg}$$
$$T_w = 61.0 \text{ °F}$$
$$T_d = 70.0 \text{ °F}$$

X7.4.1 The test station pressure, B_t, or absolute barometric pressure was measured with a mercury barometer. The actual reading of the barometer was adjusted for latitude and temperature per the mercury barometers instruction manual.

X7.4.2 The test laboratory also recorded the equivalent mean sea level barometric pressure value. This value was obtained from their local airport. It was 29.50 inHg and represented what the barometric pressure would be at 0 ft elevation not at the test laboratories elevation of 355 ft.

X7.5 The air density ratio, D_r, was computed using the values in X7.4 because these were the ambient conditions at the test location at the time of the test. D_r was calculated as follows:

$$D_r = \frac{17.68(29.10) - 0.001978(61.0)^2 + 0.1064(61.0) + 0.0024575(29.10)(70.0 - 61.0) - 2.741}{(70.0 + 459.7)}$$

$$D_r = 0.9657$$

X7.6 Using the value for D_r, the suction correction factor C_s and the input power correction factor, C_p were calculated as shown below:

$$C_s = 1 + 0.667(1 - D_r) \qquad C_p = 1 + 0.5(1 - D_r) \qquad \text{(X7.1)}$$
$$C_s = 1 + 0.667(1 - 0.9657) \qquad C_p = 1 + 0.5(1 - 0.9657)$$
$$C_s = 1.0229 \qquad C_p = 1.0172$$

X7.7 These correction factors were then used to compute the corrected suction h_s and the corrected input power P_s. In addition the airflow and air watt values were calculated for each orifice plate. The results are shown in Table X7.2.

X7.7.1 The following calculations show an example of how the corrected suction, h_s, correct input power, P_s airflow, Q, and

TABLE X7.1

Orifice Diameter (in.)	Input Power, P_s (watts)	Suction, h_s (in. H_2O)	Airflow, Q (cfm)	Air Power, AP (air watts)
2.500	768	1.70	107.2	21.4
2.000	766	3.80	101.9	45.5
1.750	761	6.00	97.7	68.8
1.500	757	9.40	88.7	97.9
1.375	750	11.70	83.6	114.8
1.250	742	14.30	76.4	128.3
1.125	731	17.70	68.7	142.8
1.000	716	21.50	60.1	151.7
0.875	693	25.70	49.8	150.3
0.750	666	30.40	39.7	141.7
0.625	637	35.20	29.6	122.3
0.500	603	40.20	20.1	94.9
0.375	566	44.50	12.2	63.7
0.250	538	47.00	5.9	32.6
0.000	519	49.30	0.0	0.0

TABLE X7.2

	Measured Data		Corrected Data (Date at Standard Conditions)			
Orifice Diameter (in.)	Input Power (watts)	Suction (in. H_2O)	Input Power, P_s (watts)	Suction, h_s (in. H_2O)	Airflow, Q (cfm)	Air Power, AP (air watts)
2.500	755	1.66	768	1.6980	107.1341	21.3483
2.000	753	3.71	766	3.7949	101.8055	45.3390
1.750	748	5.87	761	6.0044	97.7049	68.8465
1.500	744	9.19	757	9.4004	88.6998	97.8511
1.375	737	11.44	750	11.7019	83.6217	114.8346
1.250	729	13.98	742	14.3000	76.3714	128.1638
1.125	719	17.3	731	17.6960	68.8672	143.0164
1.000	704	21.02	716	21.5012	59.8448	151.0033
0.875	681	25.12	693	25.6950	49.7649	150.0619
0.750	655	29.72	666	30.4003	39.7197	141.7041
0.625	626	34.41	637	35.1977	29.6375	122.4203
0.500	593	39.3	603	40.1996	20.1266	94.9488
0.375	556	43.5	566	44.4958	12.2060	63.7367
0.250	529	45.95	538	47.0019	5.9030	32.5601
0.000	510	48.2	519	49.3034	0.0000	0.0000

the air power, *AP*, were computed for each orifice. In the calculations below the 0.750 in. diameter orifice data was used.

X7.7.1.1 The corrected suction was calculated as follows:

$$h_s = C_s h \quad \text{(X7.2)}$$

$$h_s = (1.0229)(29.72)$$

$$h_s = 30.4003$$

X7.7.1.2 The corrected input power was calculated as follows:

$$P_s = C_p P \quad \text{(X7.3)}$$

$$P_s = (1.0172)(655)$$

$$P_s = 666$$

X7.7.1.3 The airflow for the 0.750 in. diameter orifice was calculated as follows:

$$Q = 21.844\, D^2 K_1 \sqrt{h_s} \quad \text{(X7.4)}$$

$$K_1 \text{, for 0.750 in. orifice} = \frac{0.5715r - 0.5807}{r - 1.0138}$$

$$r = \frac{B_t(0.4912) - h(0.03607)}{B_t(0.4912)}$$

$$D = 0.750 \qquad B_t = 29.10$$

$$h = 29.95 \qquad h_s = 30.40$$

Solving for r:

$$r = \frac{29.10(0.4912) - 29.95(0.03607)}{29.10(0.4912)} = 0.9244 \quad \text{(X7.5)}$$

Solving for K_1:

$$K_1 = \frac{0.5715(0.9244) - 0.5807}{(0.9244) - 1.0138} = 0.5862 \quad \text{(X7.6)}$$

Solving for Q:

$$Q = 21.844(0.750)^2(0.5862)\sqrt{30.40} = 39.7197 \quad \text{(X7.7)}$$

X7.7.1.4 For the air power the calculations were as follows:

$$AP = 0.117354\, Qh_s \quad \text{(X7.8)}$$

$$AP = 0.117354\ (39.7197)(30.4003)$$

$$AP = 141.7041$$

X7.7.2 The calculations shown in X7.7.2 were made for each of the various orifice plates sizes used in the test.

X7.7.3 The maximum air power was calculated in accordance with the procedure outlined in Appendix X1 and found to be 152 air watts. This is in agreement with the vacuum cleaners characteristics described in X7.3.

X7.8 Had the independent laboratory incorrectly computed the maximum air power using the equivalent mean sea level value of barometric pressure (rather than absolute), the incorrectly calculated maximum air power would have been 150 air watts. (Based on incorrect air density ratio $D_r = 0.9790$; using $B_t = 29.50$, $T_w = 61.0°F$, and $T_d = 71.0°F$).

X7.8.1 Although the data was incorrect, the laboratory observed in their case that it did not make much difference in the results. This was due to the small difference between the test station pressure and the equivalent mean sea level value. (The small difference was a result of the test laboratory only being 355 ft above mean sea level).

X7.8.2 It is also worth noting that had the test laboratory actually tested the vacuum cleaner under the 29.50 inHg barometric pressure, the measured suction and input power values would have been slightly different for the vacuum cleaner.

TEST LOCATION 2: HIGH ELEVATION

X7.9 In El Paso, TX, an independent test laboratory located 3700 ft above sea level measured the maximum air power of the vacuum cleaner described in X7.3 per Specification F 558.

X7.10 At the test location and test time, the laboratory measured the test station pressure, B_t, the wet bulb temperature, T_w, and the dry bulb temperature, T_d. Their values were recorded as follows:

B_t=24.86 in. Hg
T_w=64.0°F
T_d=80.0°F

X7.10.1 The test station pressure, B_t, or absolute barometric pressure was measured with an aneroid barometer. The actual reading of this particular aneroid barometer gave the absolute barometric pressure value and did not need any adjustments. It was noted in the instruction manual that this barometer had temperature compensation built into it.

X7.11 The test laboratory also recorded the equivalent mean sea level barometric pressure value. This value was obtained from a digital weather station within their laboratory that had been originally set up to report the mean sea level equivalent barometric pressure to coincide with local weather reports. The value was 28.64 inHg and represented what the barometric pressure would be at 0 ft elevation not at the test laboratories elevation of 3700 ft.

X7.12 The air density ratio, D_r, was computed using the values in X7.10 as follows:

$$D_r = \frac{17.68(24.86) - 0.001978(64.0)^2 + 0.1064(64.0) + 0.0024575(24.86)(80.0 - 64.0) - 2.741}{(80.0 + 459.7)}$$

$$D_r = 0.8087$$

X7.13 Repeating the same calculation in X7.6 and X7.7 using the density ratio D_r from X7.12, the results are shown in Table X7.3.

X7.13.1 The air power was calculated to be 152 air watts.

X7.14 Had the independent laboratory incorrectly computed the maximum air power using the equivalent mean sea level value of barometric pressure (rather than absolute), the incorrectly calculated maximum air power would have been 136 air watts. (Based on incorrect air density ratio $D_r = 0.9328$; using $B_t = 28.64$, $T_w = 64.0°F$, and $T_d = 80.0°F$).

X7.14.1 Seeing the difference, the independent test laboratory realized it was very important to use the correct test station barometric pressure to ensure that the data they would distribute would correlate with other test laboratories at different elevations operating under a different air density.

TABLE X7.3

	Measured Data		Corrected Data (Data at Standard Conditions)			
Orifice Diameter (in.)	Input Power (watts)	Suction (in. H_2O)	Input Power, P_s (watts)	Suction, h_s (in. H_2O)	Airflow, Q (cfm)	Air Power, AP (air watts)
2.500	701	1.51	768	1.7026	107.2412	21.4281
2.000	699	3.37	766	3.7999	101.7847	45.3897
1.750	695	5.32	761	5.9987	97.5589	68.6790
1.500	691	8.34	757	9.4040	88.6285	97.8104
1.375	685	10.38	751	11.7043	83.5185	114.7164
1.250	677	12.68	742	14.2977	76.2585	127.9537
1.125	667	15.70	731	17.7030	68.7675	142.8659
1.000	654	19.07	717	21.5030	59.7434	150.7599
0.875	633	22.79	694	25.6976	49.7152	149.9267
0.750	608	26.96	666	30.3996	39.6695	141.5213
0.625	581	31.22	637	35.2031	29.5966	122.2699
0.500	550	35.65	603	40.1982	20.1050	94.8440
0.375	517	39.47	566	44.5056	12.1678	63.5515
0.250	491	41.68	538	46.9975	5.8739	32.3964
0.000	474	43.72	519	49.2978	0.0000	0.0000

REFERENCES

(1) "Calibration of ASTM Plenum Chamber," Whirlpool Corp., 3/31/76.

(2) *ASHRAE Guide and Data Book-Handbook of Fundamentals*, American Society of Heating, Refrigeration, and Air Conditioning Engineers, 345 E. 47th St., New York, NY 10017.

(3) *ASME Fluid Meters Theory and Application*, 6th Ed., 1971, American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017.

(4) "Fan Engineering," Buffalo Forge Co., 1970.

(5) AGA-ASME Committee Report on Orifice Coefficients, 1935.

(6) "Simplified Air Density Correction of Vacuum Cleaner Performance Data," A. L. Sebok. *Institute of Electrical and Electronics Engineers Transactions*, Vol IGA-6 January/February, 1970, pp. 88-94.

TAB F

REDACTED IN ITS ENTIRETY

TAB G

Designation: F 608 – 03

An American National Standard

Standard Test Method for Evaluation of Carpet Embedded Dirt Removal Effectiveness of Household/Commercial Vacuum Cleaners[1]

This standard is issued under the fixed designation F 608; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers only a laboratory test for determining the relative carpet dirt removal effectiveness of household/commercial vacuum cleaners when tested under specified conditions.

1.2 This test method is applicable to household/commercial types of upright, canister, and combination cleaners.

1.3 The test method applies to embedded dirt removal from carpets, not the removal of surface litter and debris.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 75 Practice for Sampling Aggregates[2]

E 11 Specification for Wire Cloth Sieves for Testing Purposes[3]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[3]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[3]

F 655 Specification for Test Carpets and Pads for Vacuum Cleaner Testing[4]

F 884 Test Method for Motor Life Evaluation of a Built-In (Central Vacuum) Vacuum Cleaner[4]

F 922 Test Method for Motor Life Evaluation of an Electric Motorized Nozzle[4]

F 1038 Test Method for Motor Life Evaluation of a Canister, Hand-held, Stick, and Utility Type Vacuum Cleaner Without a Driven Agitator[4]

F 1334 Test Method for Determining A-Weighted Sound Power Level of Vacuum Cleaners[4]

F 1409 Test Method for Straight-Line Movement of Vacuum Cleaners While Cleaning Carpets[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *cleaning ability, dry, n*—the potential of a vacuum cleaner to remove dirt from a surface (sometimes referred to in the industry as *cleanability, dry*).

3.1.2 *model, n*—the designation of a group of vacuum cleaners having identical mechanical and electrical construction with only cosmetic or nonfunctional differences.

3.1.3 *population, n*—the total of all units of a particular model vacuum cleaner being tested.

3.1.4 *repeatability limit, r*—the value below which the absolute difference between two individual test results obtained under repeatability condition may be expected to occur with a probability of approximately 0.95 (95 %).

3.1.5 *repeatability standard deviation, S_r*—the standard deviation of test results obtained under repeatability conditions.

3.1.6 *reproducibility limit, R*—the value below which the absolute difference between two test results obtained under reproducibility conditions may be expected to occur with a probability of approximately 0.95 (95 %).

3.1.7 *reproducibility standard deviation, S_R*—the standard deviation of test results obtained under reproducibility conditions.

3.1.8 *sample, n*—a group of vacuum cleaners taken from a large collection of vacuum cleaners of one particular model which serves to provide information that may be used as a basis for making a decision concerning the larger collection.

3.1.9 *test run, n*—the definitive procedure that produces a singular measured result.

3.1.10 *unit, n*—a single vacuum cleaner of the model being tested.

4. Significance and Use

4.1 This test method provides an indication of the capability of the vacuum cleaner to remove embedded dirt from carpeting. This test method is based upon results of home cleaning tests so that, in most cases, a reasonable correlation exists between home and laboratory results. The amount of dirt picked up in the laboratory test may not be the same as in the

[1] This test method is under the jurisdiction of ASTM Committee F11 on Vacuum Cleaners and is the direct responsibility of Subcommittee F11.21 on Cleanability.
Current edition approved Oct. 1, 2003. Published October 2003. Originally approved in 1975. Last previous edition approved in 2001 as F 608 – 01.

[2] *Annual Book of ASTM Standards*, Vol 04.03.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] *Annual Book of ASTM Standards*, Vol 15.08.

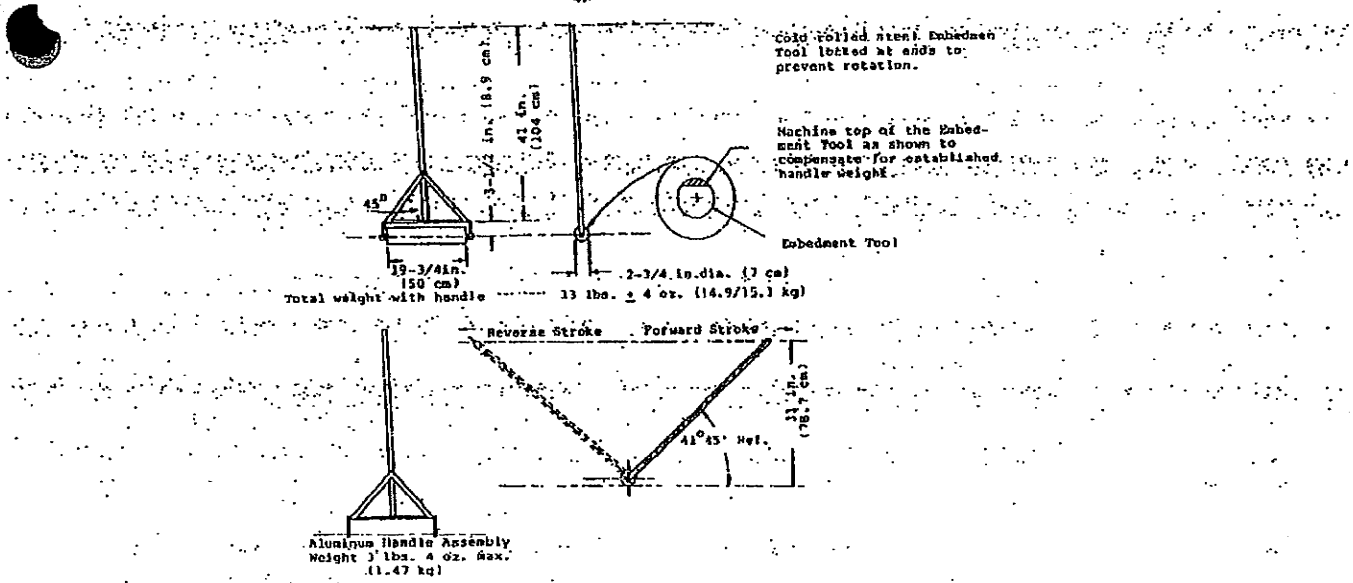


FIG. 1 Dirt Embedment Tool

home; however, it will show that, in most cases, a vacuum cleaner that performs well in the laboratory will perform well in a home. Laboratory results may differ due to variations in the homes, carpets, dirt, and other factors (see Section 6).

4.2 In order to provide a uniform basis for measuring the performance described in 1.1, standardized test carpets and a standardized test dirt are employed in this procedure.

5. Apparatus

5.1 *Weighing Scale for Weighing Carpets*, accurate to 0.035 oz (1 g) and having a weighing capacity of at least 15 lb (6.82 kg).[5]

5.2 *Weighing Scale (for Weighing Test Dirt and Dirt-Container*, (see 10.2.1.2), accurate to 0.0035 oz (0.10 g) and having a weighing capacity of at least 1.1 lb (500 g).[6]

5.3 *Stopwatch*, with a second hand or other type of equipment capable of establishing the specified rate of movement, and total cycle time.

5.4 *Voltmeter*, to measure input volts to the vacuum cleaner, to provide measurements accurate to within ±1 %.

5.5 *Voltage-Regulator System*, to control the input voltage to the vacuum cleaner. The regulator shall be capable of maintaining the vacuum cleaner's rated voltage ±1 % and rated frequency having a wave form that is essentially sinusoidal with 3 % maximum harmonic distortion for the duration of the test.

5.6 *Dirt Embedment Tool*, with the roller locked (see Fig. 1).

5.7 *Dirt Dispenser*—Dispensing system that provides the operator with a method to distribute the test dirt *uniformly* on the carpet test area.

5.8 *Carpet-Conditioning Equipment*, to support the test carpet during new carpet conditioning and the removal of residual dirt from the test carpet before each test run (Fig. 2).

5.9 *Rotating Agitator Conditioning Vacuum Cleaner/Equipment*, for conditioning new test carpets and removing residual dirt from the test carpet before each test run. This cannot be the unit being tested.

NOTE 1—Automated methods for spreading the test dirt, embedding the test dirt, and cleaning and reconditioning the test carpets are acceptable if they do not change the results of this test method.

5.10 *Temperature and Humidity Indicators*, to provide temperature measurements accurate to within ±1°F (±½ °C) and humidity measurements accurate to within 2 % relative humidity.

5.11 *Supporting Surface*—A flat surface consisting of a piece of ¾-in. (19-mm) thick exterior-grade plywood with the "A" surface upward to support the test carpet and pad. The test carpet and pad may be fastened to the supporting surface, but only the four corners, by any acceptable means.

5.12 *Rotating Agitator Reference Vacuum Cleaner*, one, for calibrating test carpets (see 10.4).

5.13 *Straight-Air Canister Reference Vacuum Cleaner*, one, for calibrating test carpets (see 10.4).

6. Materials

6.1 Standard carpets conforming to Specification F 655,

6.2 Standard carpet padding conforming to Specification F 655,

6.3 Test dirt (see Annex A1),

[5] The OHAUS Models GT-8000, LB30-CO and 1119D all available from OHAUS, Inc., Florham Park, NJ or equivalent, have been found suitable for this purpose. It is recommended that the scale read directly in grams.

[6] The Mettler-Toledo Model PM 2000, available from Mettler-Toledo, Inc. Box 71, Hightstown, NJ 08520, the OHAUS Model GT-8000 available from OHAUS, Inc. Florham Park, NJ or equivalent, have been found suitable for this purpose. It is recommended that the scale read directly in grams.

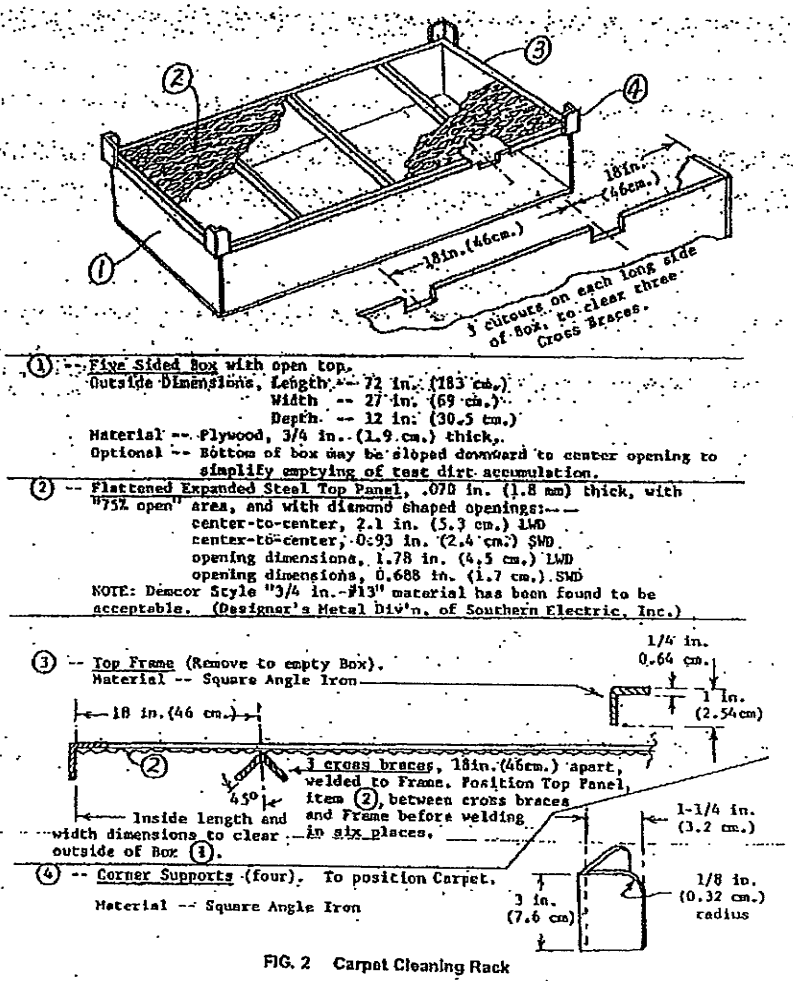


FIG. 2 Carpet Cleaning Rack

6.3.1 Silica sand (see Annex A1), and

6.3.2 Talc (see Annex A1).

7. Sampling

7.1 A minimum of three units of the same model vacuum cleaner selected at random in accordance with good statistical practice, shall constitute the population sample.

7.1.1 To determine the best estimate of cleaning ability effectiveness for the population of the vacuum cleaner model being tested, the arithmetic mean of the cleaning ability rating of the sample from the population shall be established by testing it to a 90 % confidence level within ±5 % of the mean value of the cleaning ability rating.

7.1.2 Annex A3 provides a procedural example for determining the 90 % confidence level and when the sample size shall be increased.

NOTE 2—See Annex A3 for method of determining 90 % confidence level.

8. Conditioning

8.1 *Test Room*—Maintain the test room in which all conditioning and vacuum cleaner testing is performed at 70 ± 5°F (21 ± 3°C) and 45 to 55 % relative humidity.

8.2 All components involved in the test shall remain and be exposed in the controlled environment for at least 16 h prior to the start of the test.

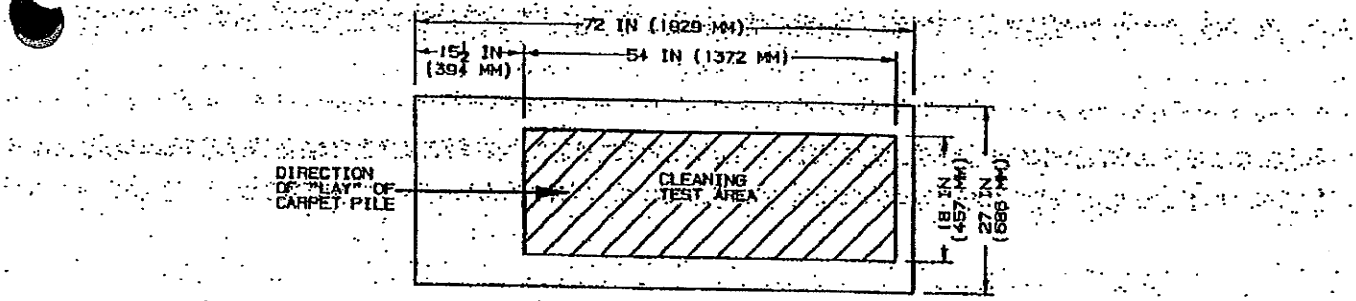
9. Test Carpets

9.1 New test carpets shall conform to Specification F 655.

9.1.1 Cut a sample of each test carpet to a size of 27 by 72 in. (690 by 1830 mm) minimum. If the warp direction or "lay" of the carpet can be determined, it shall be in the 72 in. direction as indicated in Fig. 3. Carpets shall be bound on all sides.

9.1.2 Mark the test area on each carpet as indicated in Fig. 3.

9.1.3 Precondition new test carpet samples.



NOTE 1—Cleaning test area should be positioned as shown. First forward stroke of cleaner is in direction with "lay" of carpet.

FIG. 3 Test Carpet

9.1.3.1 Precondition the entire area of the carpet by cleaning with the rotating agitator conditioning vacuum cleaner. Continue the operation until less than 2 g of carpet fiber is picked up in 5 min.

9.1.3.2 Run ten carpet-embedded dirt removal effectiveness test runs in accordance with Section 12 before conducting test calibrations in accordance with Section 11.

9.1.4 Weigh and record the preconditioned weight of the carpet.

9.1.5 Run a test carpet calibration in accordance with Section 11.

9.2 *Reconditioning Used Test Carpet Samples*:

9.2.1 To remove the residual dirt and stabilize the moisture content, clean the carpet with a rotating agitator conditioning vacuum cleaner until its weight does not exceed its previously measured, original preconditioned weight (9.1.4) by more than 2 g and less than 1 g is picked up by the conditioning vacuum cleaner after 4 min of cleaning.

9.2.2 *Procedure*:

9.2.2.1 Clean the test carpet with the rotating agitator conditioning vacuum cleaner at a rate of 1.8 ft/s (0.55 m/s) as follows:

9.2.2.2 Place the carpet on the carpet cleaning rack (Fig. 2) with pile side down. Run the rotating agitator conditioning vacuum cleaner over the carpet for 2 min concentrating on the test area; then run the rotating agitator conditioning vacuum cleaner thoroughly over the entire carpet area at least one time.

9.2.2.3 Then place the carpet (nap up) on the pad, on the plywood supporting surface and clean it with the rotating agitator conditioning vacuum cleaner for 2 min, concentrating on the test area; then run the rotating agitator vacuum cleaner thoroughly over the entire area at least one time.

9.2.2.4 Weigh the carpet.

9.2.2.5 Keep alternating 9.2.2.2 and 9.2.2.3, always ending with pile side up, until the carpet weight meets the requirements of 9.2.1.

9.2.2.6 A high-cleaning performance rotating agitator vacuum cleaner is recommended for reducing the time to recondition the carpet.

9.2.2.7 Change the disposable primary filter after a maximum of every four runs on the conditioning vacuum cleaner or more often if required.

9.3 *Reconditioning Used Carpet Padding*:

9.3.1 Clean the carpet padding by shaking after each day's testing or more often, if necessary, to remove any collected dirt.

9.3.2 Replace the carpet padding when it has holes, tears, or other signs of wear.

10. Test Vacuum Cleaners

10.1 *New Test Vacuum Cleaners*:

10.1.1 *Preconditioning a New Test Vacuum Cleaner*—Run the vacuum cleaner in at rated voltage ±1 % and rated frequency with filters in place.

10.1.1.1 *Preconditioning Rotating Agitator Type Vacuum Cleaner*—In a stationary position operate the vacuum cleaner for 1 h with the agitator bristles not engaged on any surface.

10.1.1.2 *Preconditioning a Straight-Air Canister Vacuum Cleaner*—Operate the vacuum cleaner for 1 h with a wide-open inlet (without hose).

10.1.2 For vacuum cleaners with non-disposable dirt receptacles, weigh and record the receptacle's original weight to the nearest 0.0035 oz (0.10 g).

10.2 *Used Test Vacuum Cleaners*:

10.2.1 Recondition a used test vacuum cleaner, prior to each test run as follows:

10.2.1.1 Thoroughly remove excess dirt from the vacuum cleaner. Without using tools for disassembly, clean the entire outer surface, brushes, nozzle chamber, ductwork, inside of the chamber surrounding the primary filter, and inside hose and wands.

10.2.1.2 For vacuum cleaners using disposable filters as the primary filters, use a new disposable primary filter from the manufacturer for each test. Weigh the filter to the nearest 0.0035 oz (0.10 g) and install it as recommended by the vacuum cleaner manufacturer.

10.2.1.3 For vacuum cleaners using water as the primary filter, empty the receptacle and refill as recommended by the manufacturer.

10.2.1.4 For vacuum cleaners using non-disposable dirt receptacles, empty in accordance with the manufacturer's instructions after each test run and clean the receptacle until its weight is within 0.07 oz (2 g) of its original weight. Weigh the receptacle to the nearest 0.0035 oz (0.10 g) and install it as recommended by the vacuum cleaner manufacturer.

10.3 *Test Vacuum Cleaner Settings*—If various settings are provided, set the motor speed setting, suction regulator, nozzle height, or combination thereof using the manufacturer's specifications as provided in the instruction manual for each type of carpet. Contact the manufacturer if no instructions are given, or if the instructions are unclear or inadequate.

10.3.1 All straight line movement (see Test Method F 1409), sound power (see Test Method F 1334), and motor life evaluation (see Specification F 655 and Test Methods F 884, F 922, F 1038) tests shall be conducted using the same settings (nozzle, motor speed, suction regulator, etc.) for each specific carpet.

10.4 *Reference Vacuum Cleaners (Calibration)*:

10.4.1 Use the reference vacuum cleaners only for determining the reference rating of carpets and for the verification of carpet acceptability (see Section 11).

10.4.2 Maintain the performance of the reference vacuum cleaners throughout the acceptable life of the carpet.

11. Test Carpet Calibration

11.1 The purpose of calibration is to determine when the test carpet needs to be replaced by establishing a reference rating for each new preconditioned test carpet and to check this rating every 50 or fewer test runs.

11.2 The reference ratings are determined for each test carpet by the percent pickup using the reference rotating agitator vacuum cleaner and the reference straight-air vacuum cleaner.

11.3 This percent pickup is determined by performing a carpet-embedded dirt removal effectiveness test (see Section 12).

11.4 Repeat the test carpet calibration procedure on the carpets every 50 or fewer test runs.

11.5 When the embedded dirt rating for either reference cleaner varies by 4 g from the original reference rating for the carpet, replace the carpet.

12. Carpet-Embedded Dirt Removal Effectiveness Test

12.1 Prepare test carpets in accordance with 9.1 for new carpets or 9.2 for used carpets.

12.2 Perform a calibration test, if required, in accordance with Section 11.

12.3 If preconditioning or reconditioning has been done more than 1 h before a test run, weigh the carpet. If the weight of the carpet exceeds the preconditioned or reconditioned weight by more than 2 g, clean the carpet with a rotating agitator conditioning vacuum cleaner until this criteria is met.

12.4 Position the test carpet on the padding (with "scrim" side of the padding up) on the supporting surface (see 5.11).

12.5 Prepare test cleaners and dirt receptacles in accordance with Section 10.

12.5.1 Weigh the prepared dirt receptacle (that is, dust bag or other primary filter device) prior to conducting the measurement test run. Record the weight to the nearest 0.0035 oz (0.10 g).

12.5.2 Install the primary filter as explained below:

12.5.2.1 For vacuum cleaners using disposable primary filters, install a primary filter from the manufacturer per their instructions.

12.5.2.2 For vacuum cleaners using water as the primary filter, empty and refill the receptacle as recommended by the vacuum cleaner manufacturer.

12.5.2.3 For vacuum cleaners using non-disposable primary dirt receptacles, clean the receptacle in accordance with 10.2.1.4 and install it per the manufacturer's instructions.

12.5.3 Ensure that the vacuum cleaner settings have been made in accordance with 10.3.

12.6 *Test Dirt Preparation*—Weigh and mix 3.17 ± 0.0035 oz (90 ± 0.1 g) of silica sand and 0.35 ± 0.0035 oz (10 ± 0.1 g) of commercial grade talcum, both conforming to the specifications found in Annex A1.

NOTE 3—Operator should view the Material Safety Data Sheets (MSDS) on both talc and silica sand before performing this test.

12.6.1 Silica sand shall be sieved to assure conformance to the specification of A1.2. Sieving shall be performed in accordance with Test Method D 75.

12.6.2 Bulk mixing and storage of sieved constituents of silica sand is acceptable if assay analysis meets the specification of A1.2.

12.6.3 Bulk storage of test dirt mixture (sand plus talc) is not allowed.

12.7 Distribute 3.52 oz (100 g) of the test dirt uniformly on the cleaning test area (see Fig. 3), using any convenient spreading method.

12.8 Embed the test dirt into the carpet using the dirt embedment tool shown in Fig. 1. Perform the embedding process by using a dragging motion in both directions with the handle held at the angle shown. Drag the dirt embedment tool over the test area exactly 30 strokes, alternating directions forward and back. (A movement in one direction is one "stroke.") Use a uniform movement to provide a "stroke" time of 2.5 s (a rate of 1.8 ft/s (0.55 m/s)). The first forward stroke shall be in the direction of carpet lay.

12.8.1 An acceptable laboratory practice shall be used to ensure that the dirt embedment tool shall not fall short of reaching the end boundaries of the test area, and the tool shall cover both side boundaries of the test area at all times.

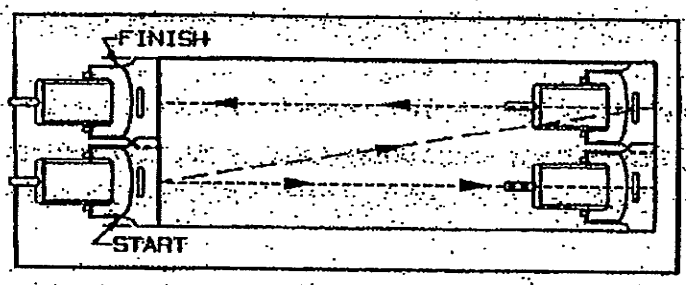
12.9 Clean the embedding tool thoroughly.

12.10 Energize the cleaner for 2 min at nameplate rated voltage (±1 %) and frequency (±1 Hz) immediately preceding the test sequence of 12.11. For vacuum cleaners with dual nameplate voltage ratings, conduct testing at the highest voltage.

12.10.1 For a rotating agitator-type vacuum cleaner, place it such that the bristles clear the supporting surface and no loose dirt is picked up.

12.10.2 For a straight-air canister vacuum cleaner, operate with the rug tool unrestricted, positioned such that no loose dirt is picked up from the supporting surface.

12.11 Immediately following the 2-min "run-in" of 12.10, deenergize the vacuum cleaner and place the vacuum cleaner nozzle on the test carpet so that the front edge of the vacuum cleaner coincides with the line defining the beginning of the test area and the right side of the boundary of the 18-in. test width (see Fig. 4). The forward stroke of the nozzle shall be in the direction of the carpet lay (see Fig. 3).



NOTE 1—This shows the nozzle positions for the cleaning pattern when $N = 2$. (Refer to Annex A2.)
FIG. 4 Cleaner Nozzle Position at Start and Finish of Test Cleaning Strokes

12.11.1 Reasonable efforts shall be made to maintain the handle height at 31.5 in. during each test run for vacuum cleaners with a pivoting handle.

12.11.2 Reasonable efforts shall be made to maintain the vacuum cleaner's nozzle parallel to the test carpet surface during each test run for vacuum cleaners with non-pivoting handles.

12.12 Tilt or lift the nozzle off the carpet, energize the vacuum cleaner, and adjust the voltage to rated voltage ±1 %. Allow the vacuum cleaner to run and expand the filter bag, if one is present.

12.13 *Test Cleaning Pattern:*

12.13.1 For a rotating agitator-type vacuum cleaner, lower the nozzle onto the carpet before the test area. Again, adjust the voltage to rated voltage ±1 %; then move the nozzle at a rate of 1.8 ft/s (0.55 m/s) in the test cleaning pattern and motion as specified in Annex A2 during the cleaning cycle. Maintain the nozzle position and settings as specified in 10.3 during the cleaning cycle.

12.13.2 For a straight-air vacuum cleaner, position the nozzle on the carpet before the test area. Again, adjust the voltage to rated voltage ±1 %; then move the nozzle at a rate of 1.8 ft/s (0.55 m/s) in the test cleaning pattern and motion as described in Annex A2. Maintain the nozzle position and settings as specified in 10.3 during the cleaning cycle.

12.14 At the end of the last stroke, smoothly tilt or lift the vacuum cleaner nozzle off the carpet and allow the vacuum cleaner to run approximately an additional 10 s to clear the system of test dirt actually picked up but temporarily trapped in it. Then deenergize the vacuum cleaner. During the additional run period, the hose used with the canister and combination vacuum cleaners should be flexed to help clear the system.

12.14.1 For vacuum cleaners with removable dirt receptacles, carefully remove the receptacle and weigh it. Record the weight to the nearest 0.10 g (0.0035 oz).

12.14.2 For vacuum cleaners using water as the primary filter, weigh the carpet to the nearest 1.0 g (0.035 oz).

12.15 Determination of the grams picked up for each test run will be done in the following manner:

12.15.1 For vacuum cleaners with removable dirt receptacles, subtract the weight of the clean dirt receptacle at the start of the test from the weight of the dirt receptacle at the end of the test. Record results to the nearest 0.10 g (0.0035 oz).

12.15.2 For vacuum cleaners using water as the primary filter, add 100 g (3.53 oz) to the weight of the carpet at the start of the test run and subtract the weight of the carpet at the end of the test run. Record results to the nearest 1.0 g (0.035 oz).

12.16 The percent carpet-embedded dirt removal effectiveness for a single test run of a given vacuum cleaner on a given carpet is the grams recorded in 12.15 divided by the 100 g, multiplied by 100.

12.17 Using the same test vacuum cleaner, repeat 12.1-12.16 two additional times for a total of three test runs.

12.18 The percent carpet-embedded dirt removal effectiveness for each individual test vacuum cleaner from the population sample is the average of three test runs meeting the repeatability statement in Section 13. See Annex A3 for a procedural example and whether further test runs need to be conducted.

12.19 A minimum of two additional test sample units of the same model shall be selected in accordance with the sampling statement of Section 7. Repeat 12.1-12.18 for each new test sample unit selected.

12.20 The percent carpet-embedded dirt removal effectiveness for the population of the vacuum cleaner model being tested is the arithmetic mean of the percent carpet-embedded dirt removal effectiveness from a sample of the population meeting the requirements of the sampling statement (Section 7).

13. Precision and Bias [7]

13.1 The following precision statements are based on interlaboratory tests involving six laboratories and two test units (one upright vacuum cleaner with agitator and one canister with straight-air floor tool).

13.2 The statistics have been calculated as recommended in Practice E 691.

13.3 The following statements regarding repeatability limit and reproducibility limit are used as directed in Practice E 177.

13.4 The standard deviations of repeatability and reproducibility of the measured results have been derived from twelve sets of data, where each of two sets of three test runs have been performed by a single analyst within each of the six laboratories on separate days using the same test unit.

13.5 *Repeatability (Single Operator and Laboratory; Multiday Testing)*—The ability of a single analyst to repeat the test within a single laboratory.

[7] Supporting data is available from ASTM Headquarters. Request RR: F11-1010.

TABLE 1 Repeatability and Reproducibility

Type Carpet	Type Cleaner	Standard Deviation of Repeatability, S_r	Repeatability Limit, r	Standard Deviation of Reproducibility, S_R	Reproducibility Limit, R
Plush	Agitator	1.006	2.816	3.4122	9.554
	Straight Air	0.720	2.015	1.806	5.05
Multi-Level	Agitator	1.105	3.094	2.177	6.095
	Straight Air	0.934	2.615	3.929	11.000
Level Loop	Agitator	1.396	3.908	2.572	7.202
	Straight Air	1.320	3.698	5.861	16.426
Shag	Agitator	0.519	1.452	1.233	3.453
	Straight Air	0.160	0.448	0.366	1.025

13.5.1 The expected standard deviation of repeatability of the measured results within a laboratory, s_r, has been found to be the respective values listed in Table 1.

13.5.2 The 95 % repeatability limit within a laboratory, r, has been found to be the respective values listed in Table 1, where $r = 2.8(s_r)$.

13.5.3 With 95 % confidence, it can be stated that within a laboratory a set of measured results derived from testing a unit should be considered suspect if the difference between any two of the three values is greater than the respective value of the repeatability limit, r, listed in Table 1.

13.5.4 If the absolute value of the difference of any pair of measured results from three test runs performed within a single laboratory is not equal to or less than the respective repeatability limit listed in Table 1, that set of test results shall be considered suspect.

13.6 *Reproducibility (Multiday Testing and Single Operator Within Multilaboratories)*—The ability to repeat the test within multiple laboratories.

13.6.1 The expected standard deviation of reproducibility of the average of a set of measured results between multiple laboratories, s_R has been found to be the respective values listed in Table 1.

13.6.2 The 95 % reproducibility limit within a laboratory, R, has been found to be the respective values listed in Table 1, where $R = 2.8(s_R)$.

13.6.3 With 95 % confidence, it can be stated that the average of the measured results from a set of three test runs performed in one laboratory, as compared to a second laboratory, should be considered suspect if the difference between those two values is greater than the respective values of the reproducibility limit, R, listed in Table 1.

13.6.4 If the absolute value of the difference between the average of the measured results from the two laboratories is not equal to or less than the respective reproducibility limit listed in Table 1, the set of results from both laboratories shall be considered suspect.

13.7 *Bias*—No justifiable statement can be made on the bias of the method to evaluate carpet-embedded dirt removal effectiveness of household/commercial vacuum cleaners. Since the true value of the property cannot be established by an acceptable referee method.

14. Keywords

14.1 dirt removal; vacuum cleaners

ANNEXES

(Mandatory Information)

A1. TEST DIRT

A1.1 *Test Dirt*, 100 g, consisting of the following:

A1.1.1 *Item 1*—90 g of silica sand[8] in accordance with A1.2.

A1.1.2 *Item 2*—10 g of commercial grade talcum[9] in accordance with A1.3.

A1.2 Silica sand in the following particle size range and amounts:

Sieve Range, U.S. No.	Particle Size, µm	Amount Used, g
−30/+40	600–425	0.9
−40/+50	425–300	31.5
−50/+70	300–212	41.4
−70/+100	212–150	13.5
−100/+140	150–106	2.7

A1.3 Commercial grade talcum with the following particle size distribution:

Particle Size Range, µm	Distribution by Weight, %
>44	0.5
43.9 to 20	12.5
19.9 to 10	27.0
9.9 to 5	23.0
4.9 to 2	20.0
1.9 to 1	8.0
<0.9	9.0

[8] Wedron No. 540 Unground Silica Sand or the equivalent has been found satisfactory for this purpose. It is available from The Wedron Silica Co., Customer Service Department, P.O. Box 119, Wedron, IL 60557. The test dirt must be sieved to ensure conformance with the analysis limits. Use Test Method D 75.

[9] USP Grade Supreme Talc or the equivalent has been found satisfactory for the purpose. It is available from Fischer Scientific Co., 1600, West Glen Avenue, Box 171, Itasca, IL 60143.

A2. TEST CLEANING PATTERN AND TIME

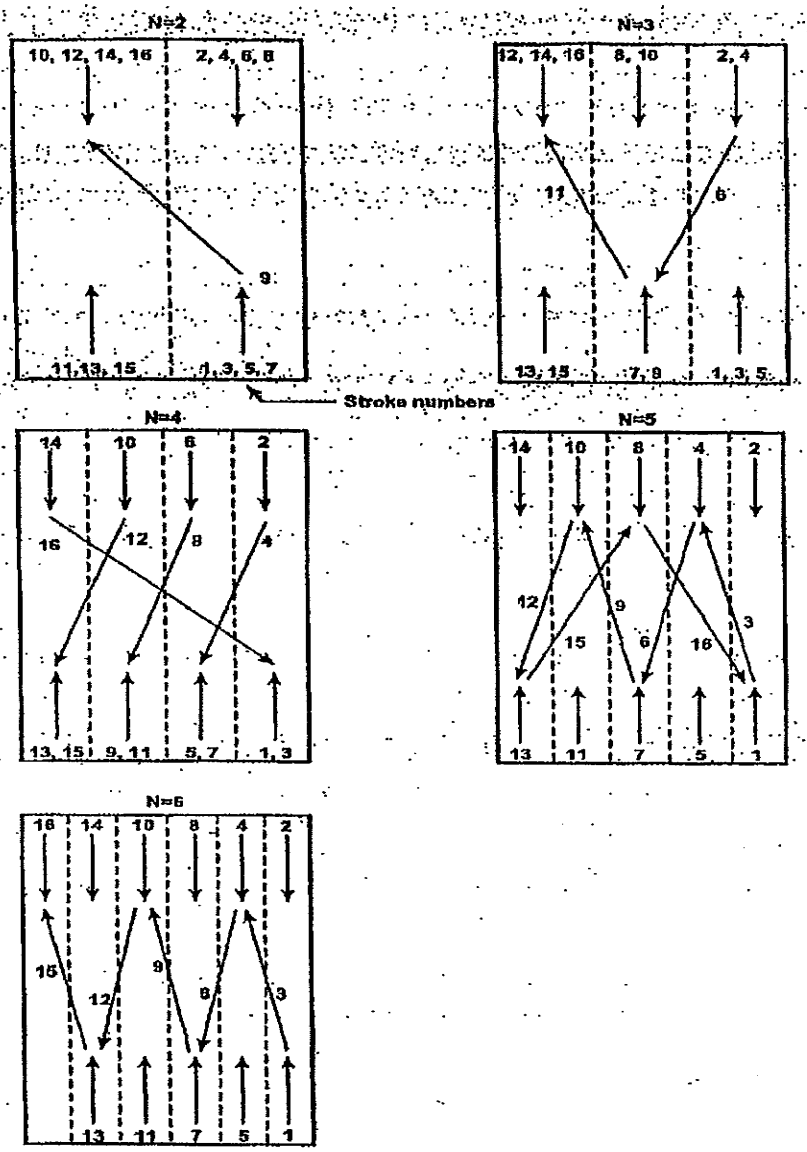
A2.1 *General*—All vacuum cleaners, regardless of the width of their nozzles, shall be moved back and forth in a specified pattern on the 54 by 18-in. (1370 by 460-mm) test area of the carpet for a total of exactly 16 strokes at the rate of 2.5 s per stroke, for a total time of 40 ± 1 s, using any acceptable laboratory method to assure that these specifications are met. Examples of methods that have been found acceptable are visible-marked timing belt or a stopwatch to measure stroke time and cumulative time.

A2.1.1 Measure the outside width of the nozzle housing in inches.

A2.1.2 Divide the nozzle width into 18 and round the result to the nearest larger whole number identified henceforth as N.

A2.1.3 Divide the width of test area (18 in.) into N equal strips and mark the test area accordingly. Note that for any vacuum cleaners having overall nozzle widths ranging from 3 to 17 in. the number of strips will be either 6, 5, 4, 3, or 2.

A2.1.4 Place the vacuum cleaner nozzle on the test carpet so that the front edge of the vacuum cleaner coincides with the line defining the beginning of the test area and the right side of the nozzle coincides with the right side boundary shown in the applicable illustration. Ensure that each forward stroke ends with the front edge of the vacuum cleaner coincident with the end of the test area. When the vacuum cleaner reaches the extreme left strip, align the left side of the nozzle with the left side boundary of the test area. See Fig. 4. This shows the pattern for $N = 2$. For variations of the pattern where $N = 2$ to $N = 6$, see Fig. A2.1. Take care to ensure that during each stroke, the side of the nozzle, right side or left side as applicable, is kept aligned with the side boundary of the test strip being cleaned, except for crossover strokes.



NOTE 1—The diagonal strokes shown in each pattern indicate that the test nozzle is moved from one stroke location to another during the diagonal stroke. There is no specific start or end point for the diagonal movement of the test nozzle during the diagonal stroke.

FIG. A2.1 Test Cleaning Patterns

A3. DETERMINATION OF THE POPULATION MEAN HAVING A 90 % CONFIDENCE INTERVAL

TABLE A3.1 Percentiles of the *t* Distribution

df	$t_{0.95}$
1	6.314
2	2.920
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.860
9	1.833
10	1.812
11	1.796
12	1.782
13	1.771
14	1.761
15	1.753

A3.1 Theory

A3.1.1 The most common and ordinarily the best estimate of the population mean, μ, is simply the arithmetic mean, $\bar{X}$, of the individual scores (measurements) of the units comprising a sample taken from the population. The average score of these units will seldom be exactly the same as the population mean; however, it is expected to be fairly close so that in using the following procedure it can be stated with 90 % confidence that the true mean of the population, μ, lies within 5 % of the calculated mean, $\bar{X}$, of the sample taken from the population.

A3.1.2 The following procedure provides a confidence interval about the sample mean which is expected to bracket μ, the true population mean, $100(1-\alpha)\%$ of the time where α is the chance of being wrong. Therefore, $1-\alpha$ is the probability or level of confidence of being correct.

A3.1.3 The desired level of confidence is $1-\alpha = 0.90$ or 90 % as stated in Section 7. Therefore $\alpha = 0.10$ or 10 %.

A3.1.4 Compute the mean, $\bar{X}$, and the standard deviation, *s*, of the individual scores of the sample taken from the population:

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad \text{(A3.1)}$$

$$s = \sqrt{\frac{n\sum_{i=1}^{n} X_i^2 - \left(\sum_{i=1}^{n} X_i\right)^2}{n(n-1)}}$$

where:

- n = number of units tested, and
- X_i = the value of the individual test unit score of the ith test unit. As will be seen in the procedural example to follow, this is the average value of the results from three test runs performed on an individual test unit with the resulting set of data meeting the repeatability requirements of Section 13.

A3.1.5 Determine the value of the *t* statistic for $n-1$ degrees of freedom, df, from Table A3.1 at a 95 % confidence level.

NOTE A3.1—The value of *t* is defined as $t_{1-\alpha/2}$ and is read as "*t* at 95 % confidence".

$$t \text{ statistic} = t_{1-\alpha/2} = t_{0.95} \qquad \text{(A3.2)}$$

where:

$1-\alpha/2 = 1-0.10/2 = 1-0.05 = 0.95$, or 95 %.

A3.1.6 The following equations establish the upper and lower limits of an interval centered about $\bar{X}$ that will provide the level of confidence required to assert that the true population mean lies within this interval:

$$CI_U = \bar{X} + ts/\sqrt{n} \qquad \text{(A3.3)}$$

$$CI_L = \bar{X} - ts/\sqrt{n}$$

where:

- CI = confidence interval (U – upper limit; L – lower limit),
- $\bar{X}$ = mean score of the sample taken from the population,
- t = *t* statistic from Table A3.1 at 95 % confidence level,
- s = standard deviation of the sample taken from the population, and
- n = number of units tested.

A3.1.7 It is desired to assert with 90 % confidence that the true population mean, μ, lies within the interval, CI_U to CI_L, centered about the sample mean, $\bar{X}$. Therefore, the quantity $ts/\sqrt{n}$ shall be less than some value, A, which shall be 5 % of $\bar{X}$ in accordance with the sampling statement of 7.1.

A3.1.8 As $n \rightarrow \infty$, $ts/\sqrt{n} \rightarrow 0$. As this relationship indicates, a numerically smaller confidence interval may be obtained by using a larger number of test units, n, for the sample. Therefore, when the standard deviation, *s*, of the sample is large and the level of confidence is not reached after testing three units, a larger sample size, *n*, shall be used.

A3.2 Procedure

A3.2.1 A graphical flow chart for the following procedure is shown in Fig. A3.1.

A3.2.2 Select three units from the population for testing as the minimum sample size.

A3.2.3 Obtain individual test unit scores by averaging the results of three test runs performed on each of the three individual test units. The data set resulting from the three test runs performed on each individual test unit shall meet the respective repeatability requirement found in Section 13.

A3.2.4 Compute $\bar{X}$ and *s* of the sample.

A3.2.5 Compute the value of *A* where $A = 0.05(\bar{X})$.

A3.2.6 Determine the statistic *t* for $n-1$ degrees of freedom from Table A3.1 where n = the number of test units.

A3.2.7 Compute $ts/\sqrt{n}$ for the sample and compare it to the value to A.

A3.2.8 If the value of $ts/\sqrt{n} > A$, an additional unit from the population shall be selected and tested, and the computations of A3.2.3-A3.2.7 repeated.

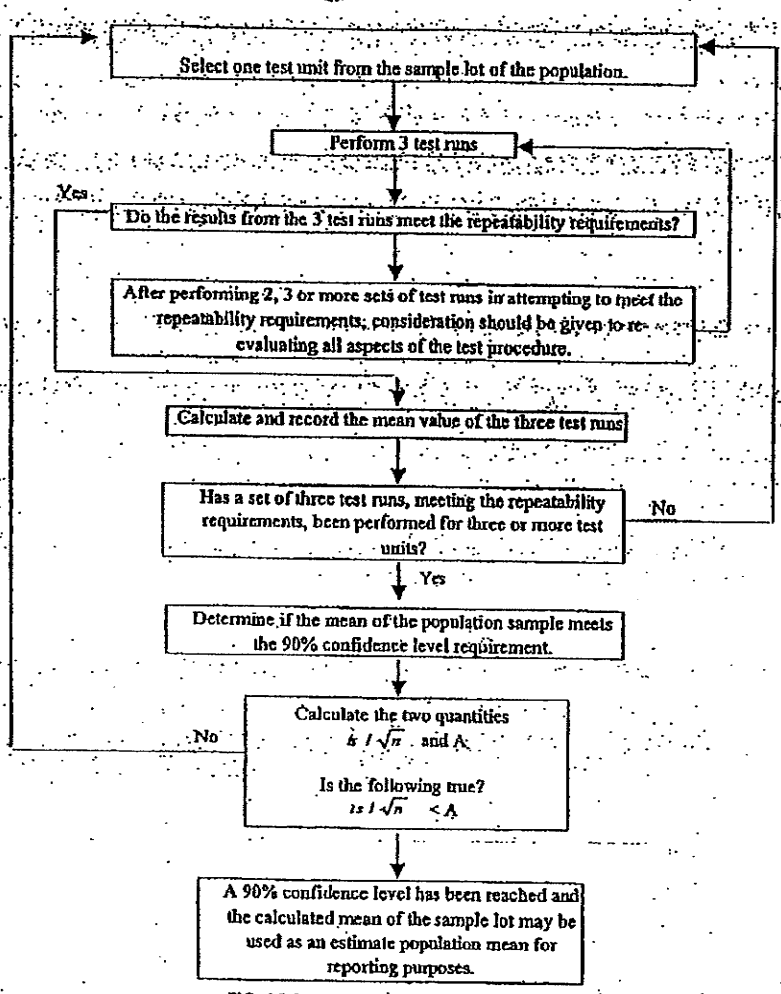


FIG. A3.1 Testing Procedure Flowchart

A3.2.9 If the value of $ts/\sqrt{n} < A$, the desired 90 % confidence level has been obtained. The value of the final $\bar{X}$ may be used as the best estimate of the cleaning ability rating for the population.

A3.3 Example

A3.3.1 The following data is chosen to illustrate how the value of embedded dirt cleaning ability for the population of an agitator type vacuum cleaner model, tested on ASTM Single-Level Loop carpet, is derived. For this particular carpet, the measured test results from three test runs on each unit are required to have a repeatability limit not exceeding 3.908 as indicated in Table 1.

A3.3.2 Select three test units from the vacuum cleaner model population. A minimum of three test runs shall be performed using each test unit.

A3.3.3 Test run scores for test unit No. 1:

test run No. 1 = 60.6
test run No. 2 = 62.7
test run No. 3 = 65.3

A3.3.4 Maximum spread = 65.3 – 60.5 = 4.8. This value is greater than the repeatability limit required in Table 1. The results shall be discarded and three additional test runs performed.

A3.3.5 Test run scores for test unit No. 1:

test run No. 4 = 64.9
test run No. 5 = 65.1
test run No. 6 = 65.8

A3.3.6 Maximum spread = 65.8 – 64.9 = 0.9. This value is less than the repeatability limit requirement of Table 1.

A3.3.7 Unit No. 1 score = (64.9 + 65.1 + 65.8)/3 = 65.27.

NOTE A3.2—If it is necessary to continue repeated test run sets (7, 8, 9–10, 11, 12—etc.) because the spread of data within a data set is not less

than the repeatability limit requirement stated in Table 1, there may be a problem with the test equipment, the execution of the test procedure, or any of the other factors involved in the test procedure. Consideration should be given to reevaluating all aspects of the test procedure for the cause(s).

A3.3.8 A minimum of two additional test units must be tested, each meeting the repeatability limit requirement. For this procedural example, assume those units met the repeatability requirement and the individual unit scores are:

Score of test unit No. 1 = 65.27
Score of test unit No. 2 = 69.53
Score of test unit No. 3 = 67.41

A3.3.9 $\bar{X} = \frac{1}{3}(65.27 + 69.53 + 67.41) = 67.403$.

A3.3.10

$$s = \sqrt{\frac{3[(65.27)^2 + (69.53)^2 + (67.41)^2] - [65.27 + 69.53 + 67.41]^2}{3(3-1)}} \quad \text{(A3.4)}$$

$$s = 2.130$$

A3.3.11 $A = 0.05\ (67.403) = 3.370$.

A3.3.12 Degrees of freedom, $n - 1 = 3 - 1 = 2$; $t_{0.95}$ statistic = 2.920.

A3.3.13 $ts/\sqrt{n} = 2.920\ (2.130)/\sqrt{3} = 3.591$.

A3.3.14 $3.591 > 3.370$ The requirement that $ts/\sqrt{n} < A$ has not been met because s is larger. Therefore, an additional test unit from the population shall be tested.

A3.3.15 Score of test unit No. 4 = 66.82.

A3.3.16 $\bar{X} = \frac{1}{4}(65.27 + 69.53 + 67.41 + 66.82) = 67.258$.

A3.3.17

$$s = \sqrt{\frac{4[(65.27)^2 + (69.53)^2 + (67.41)^2 + (66.82)^2] - [65.27 + 69.53 + 67.41 + 66.82]^2}{4(4-1)}} \quad \text{(A3.5)}$$

$$s = 1.763$$

A3.3.18 $A = 0.05\ (67.258) = 3.363$.

A3.3.19 Degrees of freedom, $n - 1 = 4 - 1 = 3$; $t_{0.95}$ statistic = 2.353.

A3.3.20 $ts/\sqrt{n} = 2.353\ (1.763)/\sqrt{4} = 2.075$.

A3.3.21 $2.075 < 3.363$ (meets requirements).

A3.3.22 Thus, the value of $\bar{X}$, 67.26, represents the embedded dirt cleaning ability score for the vacuum cleaner model tested on the given carpet and may be used as the best estimate of the cleaning ability rating for the population mean.

APPENDIX

(Nonmandatory Information)

X1. IN-HOME CLEANING TEST

X1.1 Scope

X1.1.1 The purpose of this test is to determine a ratio of a carpet-embedded dirt removal effectiveness and a home-carpet embedded removal effectiveness rating which can be used for comparing one or more vacuum cleaners against a standard vacuum cleaner and determining correlation with laboratory ASTM tests. The results are representative of the geographic area covered by the test homes.

X1.2 Summary of Method

X1.2.1 Each vacuum cleaner is tested in 25 homes in comparison with a standard vacuum cleaner. The grams of dirt picked up from the carpet in each home by each vacuum cleaner are accurately weighed. Each vacuum cleaner is manipulated over four segments of carpet 18 by 54 in. for 40 s per segment. The ratio of carpet-embedded dirt removal effectiveness equals the ratio of dirt picked up by the test vacuum cleaner (B) divided by dirt picked up by the standard vacuum cleaner (A). The home vacuum cleaning effectiveness rating of vacuum cleaner (B) to that of vacuum cleaner (A) is the geometric mean of the values obtained in the 25 individual tests performed.

X1.3 Significance

X1.3.1 The ratio of carpet-embedded dirt removal effectiveness for specific vacuum cleaner determined by "in-home" tests can be compared to "in-laboratory" tests for correlation.

X1.4 Apparatus

X1.4.1 *Standard Vacuum Cleaner for Comparison*, either upright or canister.

X1.4.2 *Frame*, inside effective area 18 by 54 in. (see Fig. X1.1):

X1.4.3 *Stop Watch*.

X1.4.4 *Canister Vacuum Cleaner*, for conditioning vacuum cleaners between tests and for finishing cleaning the remaining test area.

X1.4.5 *Dust Bags*, for appropriate vacuum cleaners.

X1.4.6 *Polyethylene Bags*, for sealing and transporting dust bags.

X1.4.7 *Balance Scale*, for weighing dust bags to within ±0.01 g.

X1.4.8 *Test Vacuum Cleaner*.

X1.4.9 *Homes*, 25 with carpeted area for selecting 6 ft area. This area must not be obstructed to traffic by furniture or scatter rugs, test homes should be randomly located throughout the graphic test area.

X1.4.10 *Adjustable Transformer*, for adjusting or controlling a voltage to the vacuum cleaner.

X1.4.11 *Voltmeter*, to measure input volts to the vacuum cleaner, provide measurements accurate to within ±1 %.

X1.4.12 *Ammeter*, to measure input current to the vacuum cleaner, provide measurements accurate to within ±1 %.

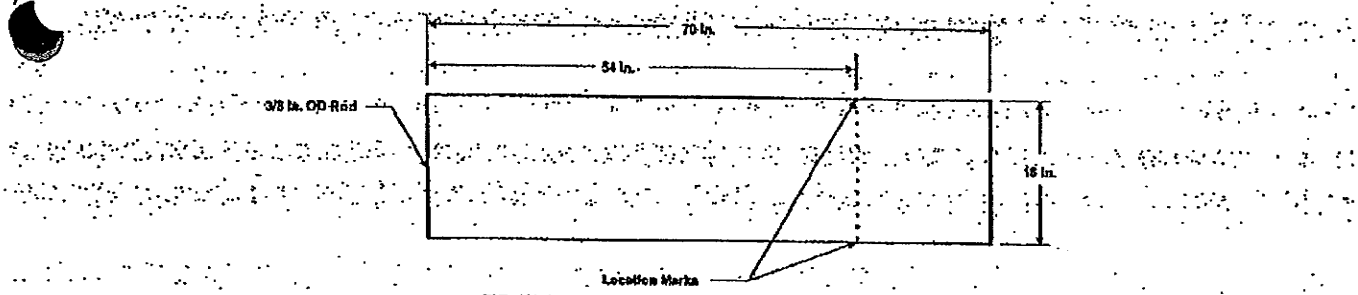


FIG. X1.1 Frame for In-Home Cleaning Test

X1.4.13 *Manometer* (or equivalent pressure-sensing device), to ensure sealed suction of the vacuum cleaner, to provide measurements in inches of water accurate to within ±0.10 in.

X1.4.14 *Tachometer(s)*, to measure motor speed in rpm and to ensure speed of agitator brush in rpm, accurate to ±1 %.

X1.5 Procedure

X1.5.1 Identify standard unit and test unit such as model number, serial number, and unit test number.

X1.5.2 *Initial Performance Check*—Check the test vacuum cleaner and the reference vacuum cleaner in the laboratory prior to the test, for functional properties. For this test, operate each vacuum cleaner at rated voltage on the ASTM Plenum Chamber using a 1¼-in. diameter orifice for upright vacuum cleaners and a ¾-in. diameter orifice for canister vacuum cleaners. Record: input current in amperes, motor speed in rpm, agitator speed in rpm, sealed suction, and agitator brush extension.

X1.5.3 Each day prior to testing in the home, check sealed suction, amperes, and brush rpm.

X1.5.4 Each vacuum cleaner is tested in 25 homes, in comparison to a standard vacuum cleaner. The test area is a 9 by 6-ft area made up of eight sections, each 18 by 54 in. (see Fig. X1.2). Areas *A* are cleaned by the known standard vacuum cleaner. Areas *B* are cleaned by the vacuum cleaner being tested. Bulky litter, such as hair pins, string, paper, etc., should be removed manually from the test area. The nozzle heights on the test and reference vacuum cleaners should be set in accordance with the specification under "Test Vacuum Cleaner Setting" in this test method.

X1.5.5 Each segment (A_1 or A_2 or B_1, etc.) should be cleaned using the same pattern of strokes, stroke time, and total time as established in this test method.

X1.5.6 The sequence of cleaning the segments of the carpet test area should be A_1, A_2, A_3, then A_4 with the standard vacuum cleaner, then B_1, B_2, B_3, then B_4 with the test vacuum cleaner.

X1.5.7 Use the frame as a guide for cleaning the 18 by 54-in. segment.

X1.5.8 Locate the test area with regard to some reference point in the home and sketch the alternative test segments *A* and *B*. Identify the carpet as to fiber, pile height, and type. Also record if padding is used under the carpet in each home tested, and the type of padding (rubber, foam, or felt).

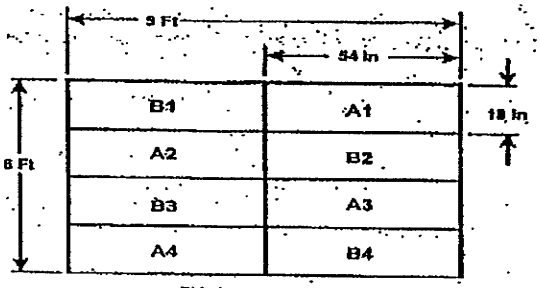


FIG. X1.2 Test Area

X1.5.9 Prior to leaving the laboratory, weigh each dust bag to the nearest ±0.01 g and record. Seal the dust bag in a polyethylene bag. Install the bag in the vacuum cleaner just prior to test. After the test, reseal the bag for transporting until time for second weighing. Then reseal and retain the bag until test is completed.

X1.5.10 Vacuum out each test unit prior to running each home test with a standby vacuum cleaner. In the case of a canister test, vacuum out the hose, wands, and nozzle between each test.

X1.5.11 Determine the dirt weight in the dust bag for the standard and for the test vacuum cleaner.

X1.6 *Data Treatment:*

X1.6.1 The ratio of carpet embedded dirt removal effectiveness for a single home is equal to the dirt picked up by Vacuum Cleaner *B* from areas $B_1 + B_2 + B_3 + B_4$ divided by the dirt picked up by Vacuum Cleaner A from areas $A_1 + A_2 + A_3 + A_4$ and is calculated as follows:

$$\text{Cleaning Effectiveness Ratio} = B/A \qquad \text{(X1.1)}$$

$$A = (A_1 + A_2 + A_3 + A_4)$$

$$B = (B_1 + B_2 + B_3 + B_4)$$

X1.6.2 The home cleaning effectiveness rating of Vacuum Cleaner B to that of Vacuum Cleaner A is the geometric mean of the values obtained in the 25 individual tests performed.

X1.7 *Cleaning Effectiveness Rating:*

$$\sqrt[N]{\left(\frac{B_1}{A_1}\right)\left(\frac{B_2}{A_2}\right)\left(\frac{B_3}{A_3}\right)\cdots\left(\frac{A_N}{B_N}\right)} \qquad \text{(X1.2)}$$

where N = number of homes in which this test was conducted.

TABS H-J

REDACTED IN THEIR ENTIRETY

TAB K

Westlaw.
Not Reported in F.Supp.2d
Not Reported in F.Supp.2d, 2004 WL 2127192 (D.Del.)
(Cite as: Not Reported in F.Supp.2d)

▷
PharmaStem Therapeutics, Inc. v. ViaCell, Inc.
D.Del.,2004.
Only the Westlaw citation is currently available.
United States District Court,D. Delaware.
PHARMASTEM THERAPEUTICS, INC., Plaintiff,
v.
VIACELL INC., et al., Defendants.
No. C.A. 02-148 GMS.

Sept. 15, 2004.

Philip A. Rovner, of Potter Anderson & Corroon LLP, Wilmington, Delaware, for Plaintiff, Paul J. André, Lisa Kobialka, of Perkins Coie LLP, Menlo Park, California, of counsel.
Jeffrey L. Moyer, of Richards Layton & Finger, Wilmington, Delaware, Richard D. Kirk, of Morris James Hitchens & Williams LLP, Wilmington, Delaware, and Robert F. Stewart, of Dilworth Paxson LLP, Wilmington, Delaware, for Defendants, Paul F. Ware, John C. Englander, James C. Rehnquist, James W. McGarry, and Elaine Herrmann Blais, of Goodwin Procter LLP, Boston, Massachussetts; William F. Abrams, Thomas F. Chaffin, and Randal Ivor-Smith, of Pillsbury Winthrop LLP, Palo Alto, California; and James L. Rodgers, Evelyn H. McCarthy, and Lisa Burgin Conte, of Dilworth Paxson LLP, Philadelphia, Pennsylvania, of counsel.

MEMORANDUM OPINION

SLEET, J.

I. INTRODUCTION

*1 On February 22, 2002, PharmaStem Therapeutics, Inc. ("PharmaStem") filed suit against ViaCell, Inc. ("ViaCell"), Cryo-Cell International, Inc. ("Cryo-Cell"), CorCell, Inc. ("CorCell"), StemCyte, Inc. ("StemCyte"), CBR Systems, Inc. ("CBR"), Birthcells Technology, Inc. ("Birthcells"), Nustem Technologies, Inc. ("Nustem"), and Bio-Cell, Inc. ("Bio-Cell") (collectively "ViaCell" or "the defendants"),[FN1] alleging infringement of United States Patents Nos. B1 5,004,681 (" '681 Patent") and 5,192,553 (" '553 Patent") (collectively "the Patents-In-Suit"). The Patents-In-Suit are generally directed toward cryopreserved therapeutic compositions containing hematopoietic stem cells obtained from umbilical cord or placental blood of a newborn, the '681 Patent, and methods pertaining to the therapeutic use of such compositions, the '553 Patent.

FN1. A default judgment was subsequently rendered against NuStem on July 10, 2002. StemCyte and PharmaStem entered a settlement agreement before trial, and StemCyte accordingly was dismissed from this action on October 21, 2003.

ViaCell asserted the defenses of invalidity for anticipation, indefiniteness, inequitable conduct and obviousness. The court held a *Markman* hearing and issued an order construing the disputed terms of the '681 and '553 Patents on January 13, 2003. A jury trial commenced on October 10, 2003. During trial, both parties properly moved for judgment as a matter of law ("JMOL") pursuant to Rule 50(a) of the Federal Rules of Civil Procedure. The court reserved ruling on all JMOL motions.

On October 29, 2003, the jury returned a unanimous verdict on all claims in favor of PharmaStem. The jury found that each of the defendants infringed the claims of the '681 and '553 Patents, and that each of the defendant's infringement of those patents was willful. The jury also upheld the validity and enforceability of the Patents-In-Suit, found that PharmaStem did not commit any anti-trust violation, and awarded PharmaStem past damages in the amount of $7,126,544.92. The court entered judgment on the verdict on October 30, 2003.

Following the jury's verdict, ViaCell filed a renewed motion for judgment as a matter of law, and, in the alternative, a motion for a new trial or for a remittitur. Defendants CBR, CorCell, and Cryo-Cell joined in Viacell's motions and submitted individual memoranda addressing issues specific to each of them. ViaCell filed another alternative motion, in which the three other defendants also joined, for findings by the court and/or to alter or amend judgment pursuant to Federal Rule of Civil Procedure 52, 59(e) and/or the court's equitable power. PharmaStem filed a motion for enhanced damages, attorneys' fees, pre-judgment interest and post judgment interest, a motion for a permanent injunction, as well as a motion to strike the affidavit of Chris Adams submitted in support of ViaCell's motion to alter or amend the judgment. Addressing

these motions collectively herein, the court will enter judgment as a matter of law that defendants do not infringe the '553 patent and grant a partial new trial on the issue of infringement of the '681 Patent.

II. STANDARDS OF REVIEW

A. Renewed Motion for Judgment as a Matter of Law

***2** Pursuant to Federal Rule of Civil Procedure 50, a court may render judgment as a matter of law after the moving party is fully heard on an issue at trial, if "there is no legally sufficient evidentiary basis for a reasonable jury to find for that party on that issue." *Walter v. Holiday Inns, Inc.*, 985 F.2d 1232, 1238 (3d Cir.1993) (citation omitted). If the court denies a motion for JMOL during trial, the motion may be renewed within ten days of entry of judgment in the case. Fed. R. Civ. P. 50(b). To prevail on a renewed motion for JMOL following a jury trial, a party " 'must show that the jury's findings, presumed or express, are not supported by substantial evidence or, if they were, that the legal conclusion(s) implied [by] the jury's verdict cannot in law be supported by those findings." ' *Pannu v. Iolab Corp.*, 155 F.3d 1344, 1348 (Fed.Cir.1998) (quoting *Perkin-Elmer Corp. v. Computervision Corp.*, 732 F.2d 888, 893 (Fed.Cir.1984)). " 'Substantial' evidence is such relevant evidence from the record taken as a whole as might be accepted by a reasonable mind as adequate to support the finding under review." *Perkin-Elmer Corp.*, 732 F.2d. at 893. In assessing the sufficiency of the evidence, the court must draw all reasonable inferences from the evidence in the light most favorable to the nonmovant. *Id.*; *Richardson-Vicks Inc. v. UpJohn Co.*, 122 F.3d 1476, 1479 (Fed.Cir.1997). The appropriate inquiry is whether a reasonable jury, given the facts before it, could have arrived at the conclusion it did. *Dawn Equip. Co. v. Kentucky Farms, Inc.*, 140 F.3d 1009, 1014 (Fed.Cir.1998). The court may not determine the credibility of the witnesses nor "substitute its choice for that of the jury between conflicting elements of the evidence." *Perkin-Elmer Corp.*, 732 F.2d at 893.

B. Motion for a New Trial

The court may grant a new trial pursuant to Federal Rule of Civil Procedure 59 "for any of the reasons for which new trials have heretofore been granted in actions of law in the courts of the United States." Fed. R. Civ. P. 59(a). A court should grant a new trial in a jury case, however, only if "the verdict was against the weight of the evidence ... [and] a miscarriage of justice would result if the verdict were to stand." *Williamson v. Consolidated Rail Corp.*, 926 F.2d 1344, 1352 (3d Cir.1991). In making this determination, the trial judge should consider the overall setting of the trial, the character of the evidence, and the complexity or simplicity of the legal principles which the jury had to apply to the facts. *Lind v. Schenley Industries, Inc.*, 278 F.2d 79, 89 (3d Cir.), *cert. denied*, 364 U.S. 835 (1960)

III. DISCUSSION

A. Defendants' Renewed Motion for Judgment as a Matter of Law

1. The Jury's Verdict That the Patents-In-Suit Are Not Obvious, Anticipated or Indefinite Is Supported by Substantial Evidence.

a. Obviousness

The defendants contend that both the '681 and '553 Patents are invalid as obvious under 35 U.S.C. § 103. Whether or not a patent is obvious over the prior art is a question of law. *See Richardson-Vicks v. Upjohn Co.*, 122 F.3d 1479, 1479 (Fed Cir.1997); *see also Karsten Mfg. Corp. v. Cleveland Golf Co.*, 242 F.3d 1376, 1384-85 (Fed Cir.2001). Section 103 provides:

***3** A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains.

35 U.S. § 103. Put simply, an invention is invalid if "the difference between the new thing and what was known before is not considered sufficiently great to warrant a patent." *Graham v. John Deere Co.*, 383 U.S. 1, 15 (1966). Obviousness cannot be based on "the hindsight combination of components selectively culled from the prior art to fit the parameters of the invention." *ADT Corp. v. Lydall, Inc.*, 159 F.3d 534, 546 (Fed Cir.1998). The Supreme Court has set forth four factors relevant to determining obviousness: (1) the scope and content of the prior art; (2) the

differences between the claimed invention and the prior art; (3) the level of ordinary skill in the art; and (4) other secondary considerations. Graham, 383 U.S. at 17-18. Evaluating the *Graham* factors in view of the evidence adduced at trial, it was not unreasonable for the jury to have concluded that the Patents-In-Suit were not obvious.

Indeed, PharmaStem proffered ample evidence to support the jury's verdict. Both a suggestion to make the composition or carry out the claimed process and a reasonable expectation of success must be found in the prior art to support a conclusion that a patent is obvious. *See* In re Vaeck, 947 F.2d 488, 493 (Fed.Cir.1991). At trial, PharmaStem presented testimony that there were problems associated with transplant tissues used prior to the Patents-In-Suit. Bernstein Tr. at 2035-2038. There was also tremendous skepticism in the transplant field regarding the use of cord blood as a transplant tissue, Bernstein Tr. at 2043-204, and the references ViaCell asserts (namely Koike, Knudtzon and Vidal) did not overcome this skepticism. Bernstein Tr. at 2045-2048, 2054-2060. Finally, testimony established that those in the field of transplantation were surprised at the result of the first cord blood transplant conducted by the inventors of the Patents-In-Suit. Bernstein Tr. at 2061-2062. *See also* Wagner Tr. at 1378-1379. It is true that ViaCell capably highlights record evidence as to the meaning one of ordinary skill would attach to the alleged prior art references. Base upon the record evidence, a jury could have found that the Patents-In-Suit were obvious. This jury, however, did not, and the aforementioned evidence provided it with sufficient basis to reach the conclusion that, prior to the inventions of the Patents-In-Suit, those in the field of hematopoietic reconstitution would not have expected cord blood to be a successful transplant tissue.

The jury also received an abundance of evidence to support the secondary considerations of long felt need, commercial success, failure of others, copying, and unexpected results. *See e.g.,* Bernstein Tr. at 2036, 2060-2061; Wagner Tr. at 1187; Tr. Ex. 413. Additionally, with respect to the '681 patent, the jury was permitted to consider the fact that the Patent and Trademark Office ("PTO") considered the alleged prior art in the reexamination and ultimate reissue of that patent. Similarly, during examination of the '553 Patent, the PTO considered the Ende, Prindull, and Knudtzon references, a fact which the jury was also entitled to consider in evaluating their combined effect on the obviousness issue. The court is not to "substitute its choice for that of the jury between conflicting elements of the evidence." Perkin-Elmer Corp., 732 F.2d at 893. In view of this standard, there is no basis to overturn the jury's finding that the Patents-In-Suit are not obvious.

b. Anticipation

***4** Likewise, the jury's finding that the Patents-In-Suit are not invalid for anticipation is supported by substantial evidence. The defendants first contend that the '681 patent is anticipated by Koike because the latter discloses each limitation of the former's claims. "An anticipating reference must describe the patented subject matter with sufficient clarity and detail to establish that the subject matter existed in the prior art and that such existence would be recognized by persons of ordinary skill in the field of the invention." The '681 Patent claims a cryopreserved therapeutic composition comprising "viable human neonatal or fetal hematopoietic stem cells derived from the umbilical cord blood or placental blood of a single human collected at the birth of said human, in which said cells are present in an amount sufficient to effect hematopoietic reconstitution of a human adult." To anticipate the '681 Patent, Koike must demonstrate that stem cells were present in umbilical cord blood. There is ample evidence in the record establishing that Koike did not demonstrate stem cells. For example, Dr. Wagner's cross examination testimony stated that Koike did not prove that there were stem cells in umbilical cord blood.[FN2] Wagner Tr. at 1333. Dr. Bernstein also testified that the reference does not teach stem cells nor a therapeutic composition for use in hematopoietic reconstitution. Bernstein Tr. at 2053. In this regard, the jury's verdict that the '681 patent is not anticipated by Koike is supported by substantial evidence so as to preclude judgment as a matter of law on the issue of anticipation.

> FN2. Dr. Wagner's cross testimony could be further construed to support the conclusion that Koike did not cryopreserve enough cord blood, or teach cryopreservation of enough cord blood, for hematopoietic reconstitution of a human, whether adult or child, which is another limitation of the '681 Patent's claims. *See* Wagner Tr. at 1342-1343.

The court reaches the same conclusion with respect to the '553 Patent. The '553 Patent claims in pertinent part:
A method for hematopoietic or immune

reconstitution of a human comprising:
(a) isolating human neonatal or fetal blood components containing hematopoietic stem cells;
(b) cryopreserving the blood components; and
(c) introducing the blood components into a suitable human host.

It is undisputed that Koike did not introduce cord blood into a human, which is a necessary limitation of the '553 Patent. The defendants claim that Koike's suggestion that introducing the stem cells into a human host should be done is a sufficiently enabling disclosure to warrant a finding of anticipation. Even so, the record contains substantial evidence from which a jury could find that a person of ordinary skill in the art would not have been so enabled. For example, Dr. Wagner testified that Koike did not do a transplant, Wagner Tr. at 1333, and Dr. Bernstein testified that Koike does not introduce stem cells into a human or teach hematopoietic reconstitution, Bernstein Tr. at 2053-2054. Again, the jury's finding that the Patents-In-Suit are not anticipated [FN3] is supported by substantial evidence and the court will not overturn it on this basis.

FN3. Given the absence of record evidence showing that Koike's compositions contained an amount of stem cells sufficient to effect hematopoietic reconstitution of a human adult, the defendants' inherent anticipation theory is an equally unpersuasive basis on which to enter judgment as a matter of law on this issue. Although recognition of an element in the prior art before the critical date is not necessary, inherent anticipation still requires that the element necessarily be present. *Schering Corp. v. Geneva Pharms.*, 339 F.3d 1373, 1377 (Fed.Cir.2003).

c. Indefiniteness

The defendants also argue that the '681 Patent is invalid because it is indefinite. Claim 1 of that patent covers "stem cells" "in an amount sufficient to effect hematopoietic reconstitution of a human adult." According to the defendants, this language is indefinite as a matter of law because it is specifically drawn to an amount of stem cells, but the patent is completely silent as to a quantity. In this regard, they claim that it does not provide sufficient notice of the scope of the invention. The court is not persuaded.

***5** Section 112 provides in pertinent part:

The specification shall contain a written description of the invention, and of the manner and process of making and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same, and shall set forth the best mode contemplated by the inventor of carrying out his invention.

35 U.S.C. § 112. The statute requires the patentee to provide the public with clear notice of what activities infringe the patent. *See Exxon Research & Eng'g Co. v. United States*, 265 F.3d 1371, 1375 (Fed.Cir.2001); *Morton Int'l v. Cardinal Chem. Co.*, 5 F.3d 1464, 1470 (Fed.Cir.1993). "If the claims, read in light of the specifications, reasonably apprise those skilled in the art both of the utilization and scope of the invention, and if the language is as precise as the subject matter permits, the courts can demand no more." *Shatterproof Glass Cor. v. Libbey-Woens Ford Co.*, 758 F.2d 613 624 (Fed.Cir.1985) (citing *Georgia Pacific Corp. v. United States Plywood Corp.*, 258 F.2d 124, 136 (2d Cir.1958)). Indefiniteness is a question of law for the court. *In re Jolly*, 172 F.2d 566, 570 (C.C.P.A.1949); *see also Union Pacific Res. Co. v. Chesapeake Energy Corp.*, 236 F.3d 684, 692 (Fed.Cir.2001). "In a jury trial, if there are disputed factual issues related to indefiniteness, they may be submitted to the jury for resolution." *Union Carbide Chems. & Plastics Tech. Corp. v. Shell Oil Co.*, Nos. 99-274(SLR), 99-876(SLR), 2004 WL 1305849, *10 (D.Del.2004) (citing *BJ Services Co. v. Halliburton Energy Serv., Inc.*, 338 F .3d 1368, 1372 (Fed.Cir.2003)). Because a patent is presumed valid, the party asserting a defense of invalidity on the basis of claim indefiniteness bears the burden of proof by clear and convincing evidence. *See Orthokinetics, Inc. v. Safety Travel Chairs, Inc.*, 806 F.2d 1565, 1575-76 (Fed.Cir.1986).

It is true that the language of the '681 Patent does not specify an amount of progenitor cells nor a volume of cord blood, and the specification is silent as to a precise amount. However, these facts do not necessarily dictate that Claim 1 must fail for indefiniteness. Given that there is no determinate or determinable minimum amount of cord blood for therapeutic usefulness in humans, the record supports that the '681 Patent's claim language is as precise as the subject matter permits. Moreover, the record contains evidence establishing that a person of skill in the art would have understood what an amount of cord blood stem cells sufficient to effect hematopoietic reconstitution of a human adult means.

See Andrew Corp. v. Gabriel Electronics, Inc., 847 F.2d 819, 823 (Fed.Cir.1988); *Hybritech Inc. v. Monoclonal Antibodies, Inc.*, 802 F.2d 1367, 1385 (Fed.Cir.1986). Dr. Moore, PharmaStem's expert on hematopoiesis, testified that the Patents-In-Suit provide the reader with ample information to determine the amount of cord blood needed for transplantation in adults or children, and that the scientific community has in fact performed numerous transplants into adults. Moore Tr. at 340-348; *see also* Harris Tr. at 635-636 (for defendants' witness skilled in art stating that an amount sufficient for usefulness in a clinical setting would be "a sample that contained enough of those cells for a successful transplant"). Thus, the court can find no basis to overturn the jury's verdict that the '681 Patent is not invalid for indefiniteness.

2. The Jury's Verdict That the Defendants Contributorily Infringe the '553 Patent Cannot Stand.

***6** The defendants claim that PharmaStem did not prove that they contributorily infringed the '553 Patent in that PharmaStem failed to adduce evidence that any of them sold or offered to sell cryopreserved cord blood to a transplanter or that cryopreserved cord blood was used by a single entity or group of entities acting in concert or working together to infringe the patent. The court agrees. Relevantly, the claim language of the '553 Patent requires:
A method for obtaining human neonatal or fetal hematopoietic stem or progenitor cells comprising:
(a) isolating human neonatal or fetal blood components containing hematopoietic stem or progenitor cells;
(b) cryopreserving the blood components; and
(c) thawing the blood components, such that the stem or progenitor cells are viable.

Because none of the defendants thaw or inject cord blood, both required elements of the '553 Patent's claims, there can be no literal infringement of the '553 Patent.

PharmaStem would, however, still be entitled to a finding of infringement if the jury reasonably could have found that the defendants contributorily infringed the '553 patent. *See* 35 U.S.C. § 271(c).

Section 271(c) states:
Whoever offers to sell or sells within the United States or imports into the United States a component of a patented machine, manufacture, combination or composition, or a material or apparatus for use in practicing a patented process, constituting a material part of the invention, knowing the same to be especially made or especially adapted for use in an infringement of such patent, and not a staple article or commodity of commerce suitable for substantial noninfringing use, shall be liable as a contributory infringer.

35 U.S.C. § 271. The verdict form required the jury to answer three questions in the affirmative in order to find that any of the defendants contributorily infringed the '553 patent. Consistent with the appropriate legal standard, the jury was required to find that (I) "cryopreserved cord blood has no substantial noninfringing use," (ii) "defendants and transplant physicians are acting in concert or working together to complete the process of infringement of claims 13, 19, 47, or 57 of the '553 patent by performing each and every one of the steps in any of those claims," and (iii) "a Defendant has contributorily infringed the '553 patent by selling or offering to sell cryopreserved cord blood that was actually used by a third party in the direct infringement of any of claims 13, 19, 47, 53, or 57 of the '553 patent." Jury Verdict Form, Qtn. Nos. 3, 4, and 5.

PharmaStem correctly points out the existence of evidence to support the jury's affirmative answer to questions (I) and (ii) of the verdict form. The record supports a conclusion that cryopreserved cord blood is, predominantly, useful only for transplantation therapy, or the use covered by the '553 Patent. Indeed, PharmaStem adduced evidence by which a jury reasonably could have found that cord blood was viewed as medical waste prior to the inventions of the Patents-In-Suit. *See, e.g.,* Moore Tr. at 328; Broxmeyer Tr. at 365; Wagner Tr. 1195-1196.

***7** Moreover, the jury also could have reasonably found that each of the defendants worked together with transplant physicians to complete the patented process of the asserted claims of the '553 Patent. At trial, PharmaStem adduced evidence that the defendants test the blood samples to ensure each one is sufficient for transplantation and thereby aid transplant physicians. Tr. Ex. 103; Tr. Ex. 96; Laleman Tr. at 659. The defendants marketing materials also indicate that they work with physicians in various capacities to effectuate the transplantation process. For example, CorCell's website states "CorCell and Community Blood Services (CBS) has formed a strategic partnership devoted to expertly testing, processing and storing quality cord blood stem cells for future transplantation." Tr. Ex. 516.

ViaCell's founder, Cynthia Fisher, testified that the company's mission was "to provide a niche application area between the obstetrician, the Hem/Onc and the blood banking center, as far as enabling providing cord blood stem cell banking." Fisher Tr. at 707. Cryo-Cell advertises that the units of cord blood stem cells stored at its facility are transplant-ready. Tr. Ex. 98. In addition, PharmaStem presented evidence that each of the defendants has at least one representative who liaises in some capacity with transplant physicians, i.e., Dr. Goldberg of CorCell and Dr. O'Neil of Cryo-Cell. CBR designates a Director of the Facility to oversee procedures regarding the release of cord blood units for transplantation. Tr. Ex. 110. Viacell seeks advice and counsel on nucleated cell counts and volumes useful for transplantation from its Medical Scientific Advisory Board, on which five of the seven members are prominent transplant doctors or physicians with extensive experience in hematology, oncology, and/or transfusion medicine. Tr. Ex. 253, Tr. at 1461-63; *see also* Wagner Tr. at 1389. Finally, there is also evidence in the record showing that each of the defendants maintain records and/or other materials regarding its cord blood units which it releases to physicians to assist the transplantation process. CorCell maintains records on the cord blood units it releases, Tr. Ex. 274, and requests feedback from the transplant facility as part of its standard operating procedures, Tr. Ex. 215. Cryo-Cell provides directions to transplant physicians on how to thaw the cryopreserved cord blood unit it provides. Tr. Ex. 97. CBR has a similar document setting forth the detailed protocol between CBR and the transplant physician when a cord blood unit is requested and released. Tr. Ex. 110. In view of this evidence, it was not unreasonable for the jury to have found that the defendants and transplant physicians worked together to infringe the '553 patent.

Nevertheless, with respect to the third question on the verdict form, there is simply no evidence in the record to support the jury's affirmative answer. It is undisputed that the defendants do not own the cord blood units. Rather the units are owned by the clients, or families, and the defendants in turn provide services with respect to the processing and storing of the compositions. Although the defendants charge enrollment, processing, and banking fees with respect to their storage services, they do not *sell* or *offer to sell* the cord blood units. Indeed, the record evidence on this issue is clear that the defendants sell a service, not cord blood units. *See* Hendrix Tr. 1042; Tr. 2653; Wagner Tr. 1278.

***8** Tellingly, PharmaStem cannot direct the court to a single fact in evidence that would support a finding that any of the defendants sell or offer to sell cord blood. PharmaStem attempts to overcome this deficiency in the record by arguing that Section 271(c) focuses on the financial benefit derived by the seller regardless of the source. But the statute could not be clearer. Section 271(c) liability is clearly dependant upon the accused infringer's selling or offering to sell a component of the patented process, here cord blood units. *See* 35 U.S.C. § 271(c). Drawing all reasonable inferences from the evidence in favor of PharmaStem, the court agrees with the defendants that the jury's finding on the element of contributory infringement is not supported by substantial evidence. In this regard, the jury's verdict on contributory infringement cannot stand. The court finds as matter of law that the defendants' services do not infringe the '553 patent.[FN4]

FN4. Because the court finds that the defendants do not infringe the '553 Patent, it will not address the issue of willful infringement with respect to that patent.

B. Defendants' Motion for a New Trial

The defendants alternatively contend that the court should set aside the judgment and grant a new trial because the jury's verdict was against the great weight of the evidence. The court agrees with respect to the jury's finding that the 100% of the defendants' cord blood units infringe the '681 patent and accordingly will grant a partial new trial on this issue.

1. Inventorship

The defendants first claim that a new trial is warranted because the great weight of the evidence established that the Patents-In-Suit are invalid for failure to name one of the inventors, Dr. Pablo Rubinstein. The court does not agree.

Every patent receives the presumption that its inventors are the true and only inventors. *See e.g., Acromed Corp. v. Sofamor Danek Grp., Inc.*, 253 F.3d 1371, 1379 (Fed.Cir.2001). Invalidity for failure to name an inventor must be established by clear and convincing evidence. *See id.* at 1379. To be a joint inventor, one must "contribute in some significant manner to the conception of the invention." *Fina Oil & Chem. Co. v. Ewen*, 123 F.3d 1466, 1473 (Fed.Cir.1997). Specifically, each person claiming to

be an inventor must have contributed to the conception of the invention. *Acromed*, 253 F.3d at 1379. Beyond conception, the purported inventor must demonstrate that he made "a contribution to the claimed invention that is not insignificant in quality, when contribution is measured against the dimension of the full invention, and [did] more than merely explain to the real inventors well-known concepts and/or the current state of the art." *Id.* at 1379.

Although the defendants point to evidence from which a jury could have found Dr. Rubinstein's contributions to be significant, PharmaStem adduced at least an equal amount of evidence that his contribution did not rise to the level of inventorship. Indeed, a jury could conclude from the record that Dr. Rubinstein provided consultation on cryopreservation methods which were already available in the art. *See* Bernstein Tr. at 1176-1177. Moreover, Dr. Rubinstein admitted that he published his cryopreservation techniques more than one year prior to the inventions of the Patents-In-Suit, Rubinstein Tr. at 1176-1177, which would allow a jury to conclude that any contribution he made was rendered prior art by the time of the patenting of the invention. *See* 35 U.S.C. § 102; *Hess v. Advanced Cardiovascular Syss.*, 106 F.3d 976, 981 (Fed.Cir.197). In light of these significant pieces of evidence supporting the jury's finding that Dr. Rubinstein was not improperly omitted as an inventor, the court finds no basis to grant a new trial on the issue of invalidity for failure to name an inventor.

2. Inequitable Conduct

***9** The defendants also argue that the jury's finding that PharmaStem did not engage in inequitable conduct before the PTO in the procurement of the '681 and '553 Patents is against the great weight of the evidence. The court, however, is not persuaded that the jury's finding on this issue warrants a new trial. The burden is on the party seeking to invalidate the patents to prove inequitable conduct by clear and convincing evidence. In view of the defendants' burden, the jury's verdict was not against the great weight of the evidence.

As evidence of PharmaStem's alleged inequitable conduct, the defendants point to the PharmaStem's failure to disclose two pieces of information to the PTO. First, after PharmaStem had presented its arguments to the PTO in reexamination, but several months before the '681 Patent reissued, the European Patent Office ("EPO") denied PharmaStem's European counterpart application, rejecting its argument that Koike does not teach stem cells. PharmaStem did not bring the EPO's rejection of its argument to the attention of the PTO before reissue. Second, in its opinion, the EPO cites the 1997 Broxmeyer article for the proposition that relevant scientific community considered progenitor cell assays to be reliable assays for stem cells. In view of these facts, the defendants argue that the jury's finding that PharmaStem did not engage in inequitable conduct before the PTO is against the great weight of the evidence.

"One who alleges inequitable conduct arising from a failure to disclose prior art must offer clear and convincing proof of the materiality of the prior art, knowledge chargeable to the applicant of that prior art and of its materiality, and the applicant's failure to disclose the prior art, coupled with an intent to mislead the PTO." *Molins*, 48 F.3d at 1178; *accord Rockwell Techs., LLC v. Spectra Physics Lasers, Inc.*, 2002 WL 531555, at *3 (D.Del. Mar. 26, 2002). "Materiality and intent to deceive are distinct factual inquiries, and each must be shown by clear and convincing evidence." *Life Techs., Inc. v. Clontech Labs., Inc.*, 224 F.3d 1320, 1324 (Fed.Cir.2000); *accord Isco Int'l, Inc. v. Conductus, Inc.*, 2003 WL 22006253, at *6 (D.Del. Aug. 21, 2003). Patent applicants have a duty to disclose to the PTO "any material prior art or other information cited or brought to their attention in any related foreign application." Manual of Patent Examining Procedure § 2001.06(a) (4th ed., rev.8, Oct. 1981). However, a finding of inequitable conduct for nondisclosure of information requires proof that the applicant made a deliberate decision to withhold a known material reference from the PTO. *See Molins PLC v. Textron, Inc.*, 48 F.3d 1172, 1181 (Fed.Cir.1995).

Given the controlling standards, PharmaStem adduced significant evidence to rebut the defendants' inequitable conduct case. Specifically, the EPO's decision applied European, as opposed to United States, patent laws, and examined different claims than the ones at issue before the PTO in the reexamination. Tr. Ex. 1013. Moreover, there is no dispute that PharmaStem disclosed Koike to the PTO in the reexamination, and that the PTO came to its own conclusion as to what the reference taught. With respect to the Broxmeyer article, it was published nearly ten years after the initial filing of the Patents-In-Suit, and therefore not a prior art reference. Tr. Ex. 1015. Further lending credence to PharmaStem's view that the article was not material, the EPO

characterized the Broxmeyer article as "indirect evidence" and cited it in the portion of the opinion on novelty, which was not at issue in the reexamination before the PTO. Tr. Ex. 1013. When viewed as a whole, the record more than supports a conclusion that PharmaStem did not possess the requisite intent to deceive the PTO and therefore did not engage in inequitable conduct.

3. Infringement of the '681 Patent

a. Dr. Hendrix's Testimony

***10** As one of the bases for their motion for a new trial on infringement of the '681 Patent, the defendants contend that Dr. Mary Hendrix, PharmaStem's infringement expert, should not have been permitted to testify. During the pretrial stage of proceedings, the defendants objected to Dr. Hendrix's testimony in a motion *in limine* and then again at the close of trial moved to strike the doctor's testimony. The court denied both of these motions, but will revisit its rulings in light of the evidentiary record now before it.

Rule 702 has three requirements as to expert opinions: 1) the witness must be an expert; (2) the witness must testify to scientific, technical, or other specialized knowledge; and 3) the testimony must assist the trier of fact. *See* *United States v. Velasquez*, 64 F.3d 844, 849 (3d Cir.1995) (citations omitted). The U.S. Supreme Court's decision in *Daubert v. Merrell Dow Pharmaceuticals*, 509 U.S. 579 (1993), established a gatekeeping role for trial court judges in determining the admissibility of expert testimony on scientific evidence. When an expert bases opinion testimony on scientific knowledge, the testimony will not be admitted unless it is derived by the scientific method and is supported by "appropriate validation." *Daubert*, at 590. This standard of evidentiary reliability focuses on the scientific validity of the expert's methods rather than the soundness of his specific conclusions. *Id. at 589* ("[the] inquiry into the reliability of scientific evidence .... requires a determination as to its scientific validity."); *see also* *Oddi v. Ford Motor Co.*, 234 F.3d 136, 145 (3d Cir.2000); *United States v. Shea*, 957 F.Supp. at 337. An expert's opinion is reliable if it is based on the "methods and procedures of science" rather than on "subjective belief or unsupported speculation"; the expert must have "good grounds" for his or her belief. *See* *Daubert*, 509 U.S. at 589.

The defendants contend that the subject of Dr. Hendrix's testimony was not one for which expertise was necessary in that she based her infringement opinion entirely on an analysis of the defendants' marketing materials, without ever considering any data regarding the composition of the defendants' cord blood units. Dr. Hendrix is an accomplished stem cell biologist, but is not qualified as an expert in marketing or advertising. Moreover, her so-called analysis of the defendants' marketing materials was well within the jury's common knowledge, common sense and common experience. *See* *United States v. Stevens*, 935 F.2d 1380, 1399-1400 (3d Cir.1991) (upholding Federal Rule of Evidence 403 exclusion of expert testimony regarding eye witness identification where the evidence was susceptible of elucidation without specialized knowledge and jury could have ascertained through common sense). In view of these considerations, the court is persuaded that Dr. Hendrix's conclusion, evidenced in her expert report and adduced through her testimony, that 100% of the defendants' cord blood units infringe the '681 Patent was based upon a legally improper methodology that was unreliable as a matter of law under *Daubert.*

***11** Significantly, Dr. Hendrix's admitted that she did not review or analyze any of the defendants' cord blood samples in reaching her opinion. Hendrix Tr. at 1038. Moreover, she explicitly testified that her opinion that all of the defendants' cord blood units infringe the '681 Patent was based on the fact that the defendants "promise stem cells for pediatric and adult transplantation." Hendrix Tr. at 1021. In this regard, her opinions are not based upon any methods or procedures of science in general and certainly not upon her specific expertise as a stem cell biologist, no matter how knowledgeable she may have been in that field. The court therefore determines that her opinion of infringement is no more than a lay-person's interpretation of the defendants' marketing materials. The materials relied upon by Dr. Hendrix may be persuasive on the issue of infringement, but permitting PharmaStem to couch its presentation of this evidence in the form of an expert opinion was an error.

b. The Lack of Record Evidence that 100% of the Defendants' Units Infringe the '681 Patent

Claim 1 of the '681 Patent covers compositions containing stem cells "in an amount sufficient to effect hematopoietic reconstitution of a human adult." To prove infringement, therefore,

PharmaStem was required to adduce evidence that the defendants cord blood units contained an amount of stem cells sufficient for transplantation into an adult. In the absence of Dr. Hendrix's testimony, the record is void of any proof to support a finding that 100% of the defendants' cord blood units infringe the '681 Patent. To the contrary, the record overwhelmingly indicates that cord blood units will *not all* contain sufficient cells to reconstitute an adult. *See* Wagner Tr. at 1270; *see also* Tr. Ex. 1370 at 30 (PharmaStem telling the PTO that cord blood units "are highly variable in their stem cell content such that any particular cord blood collection may have low or no stem cells"). The jury's finding that *all* of the defendants' cord blood units infringe the '681 Patent, consequently, was against the great weight of the evidence.

At the same time, however, the record suggests that at least some of the defendants' cord blood units infringe in that there is evidence of successful transplants of the defendants' compositions into human adults. *See, e.g.,* Tr. Ex 115 (circumstantial evidence in the form of statements on CBR's website that a "newborn's cord blood stem cells were transplanted to her mother to treat chronic myelogenous leukemia," and that other transplants have occurred for the newborn's mother father and cousin); Tr. Ex. 103 (draft of ViaCord's private placement memorandum acknowledging that adult transplants have occurred). As a result, the court will grant a new trial, excluding Dr. Hendrix's expert testimony, on the issue of infringement of the '681 Patent and the resultant damages therefrom.[FN5]

FN5. Again, in light of its granting a new trial on the infringement issue, the court will not rule on the issue of willful infringement with respect to the '681 Patent.

IV. CONCLUSION

For the aforementioned reasons, the court will enter judgment as a matter of law that the defendants do not infringe the '553 Patent and grant a new trial on the issue of infringement and damages with respect to the '681 Patent. In all other aspects, the motions filed by the parties are denied. An order to this effect will accompany this opinion.

ORDER

***12** For the reasons set forth in the court's memorandum opinion issued contemporaneously herewith, IT IS HEREBY ORDERED that:

1. Joint Renewed Motion by ViaCell, Inc, Cyro-Cell, Inc, CorCell, Inc, CBR Systems, Inc. for Judgment as a Matter of Law or in the Alternative, for a New Trial (or for Remittitur) (D.I.448) is GRANTED IN PART.
2. PharmaStem, Inc.'s Motion for Enhanced Damages, Attorneys' Fees, Pre-Judgment Interest and Post Judgment Interest (D.I.446) is DENIED.
3. PharmaStem, Inc.'s Motion for a Permanent Injunction (D.I.447) is DENIED.
4. PharmaStem's Motion to Strike the Affidavit of Chris Adams (D .I. 487) is DENIED as moot.
5. The clerk shall enter judgment in favor of the defendants and against the plaintiff on the claim of infringement of U.S. Patent No. 5,192,553.
6. A new trial shall be held on the issue of infringement and damages with respect to U.S. Patent No. 5,004,681.

D.Del.,2004.
PharmaStem Therapeutics, Inc. v. ViaCell, Inc.
Not Reported in F.Supp.2d, 2004 WL 2127192 (D.Del.)

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